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Chiappetta

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(54) **CELESTIAL NAVIGATION SYSTEM FOR AN AUTONOMOUS VEHICLE**

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CPC ***G06F 17/00*** (2013.01); ***G05D 1/0225*** (2013.01); ***G05D 1/0242*** (2013.01); *G05D 2201/0203* (2013.01); *Y10S 901/01* (2013.01)

(58) **Field of Classification Search**

USPC 700/245–264

See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

1,755,054	A	4/1930	Darst
1,780,221	A	11/1930	Buchmann
1,970,302	A	8/1934	Gerhardt
2,136,324	A	11/1938	John
2,302,111	A	11/1942	Dow et al.

(Continued)

FOREIGN PATENT DOCUMENTS

DE	2128842	C3	12/1980
DE	3317376	C2	12/1987

(Continued)

OTHER PUBLICATIONS

Aly et al., "CompactKdt: Compact Signatures for Accurate Large Scale Object Recognition," IEEE Workshop on Applications of Computer Vision (WACV), *IEEE*, Jan. 9-11, 2012, Breckenridge, CO, pp. 505-512.

(Continued)

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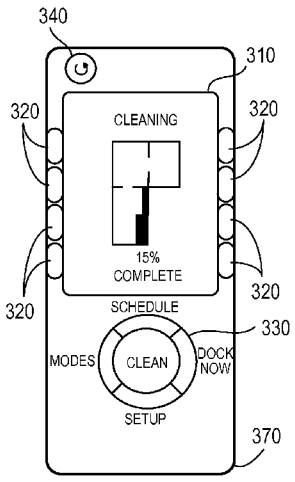
(57) **ABSTRACT**

A navigation control system for an autonomous vehicle comprises a transmitter and an autonomous vehicle. The transmitter comprises an emitter for emitting at least one signal, a power source for powering the emitter, a device for capturing wireless energy to charge the power source, and a printed circuit board for converting the captured wireless energy to a form for charging the power source. The autonomous vehicle operates within a working area and comprises a receiver for detecting the at least one signal emitted by the emitter, and a processor for determining a relative location of the autonomous vehicle within the working area based on the signal emitted by the emitter.

15 Claims, 24 Drawing Sheets



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continuation-in-part of application No. 12/415,512, filed on Mar. 31, 2009, now Pat. No. 8,634,956, which is a continuation of application No. 11/176,048, filed on Jul. 7, 2005, now Pat. No. 7,706,917.

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(56) **References Cited**

U.S. PATENT DOCUMENTS

2,353,621	A	7/1944	Sav et al.
2,770,825	A	11/1956	Pullen
2,930,055	A	3/1960	Fallen et al.
3,119,369	A	1/1964	Harland et al.
3,166,138	A	1/1965	Dunn
3,333,564	A	8/1967	Waters
3,375,375	A	3/1968	Robert et al.
3,381,652	A	5/1968	Schaefer et al.
3,457,575	A	7/1969	Bienek
3,550,714	A	12/1970	Bellinger
3,569,727	A	3/1971	Aggarwal et al.
3,649,981	A	3/1972	Woodworth
3,674,316	A	7/1972	De Bray
3,678,882	A	7/1972	Kinsella
3,690,559	A	9/1972	Rudloff
3,744,586	A	7/1973	Leinauer
3,756,667	A	9/1973	Bombardier et al.
3,809,004	A	5/1974	Leonheart
3,816,004	A	6/1974	Bignardi
3,845,831	A	11/1974	James
RE28,268	E	12/1974	Autrand
3,851,349	A	12/1974	Lowder
3,853,086	A	12/1974	Asplund
3,863,285	A	2/1975	Hukuba
3,888,181	A	6/1975	Kups
3,937,174	A	2/1976	Haaga
3,952,361	A	4/1976	Wilkins
3,989,311	A	11/1976	Debrey
3,989,931	A	11/1976	Phillips
4,004,313	A	1/1977	Capra
4,012,681	A	3/1977	Finger et al.
4,070,170	A	1/1978	Leinfelt
4,099,284	A	7/1978	Shinozaki et al.
4,119,900	A	10/1978	Kremnitz
4,175,589	A	11/1979	Nakamura et al.
4,175,892	A	11/1979	De bray
4,196,727	A	4/1980	Verkaart et al.
4,198,727	A	4/1980	Farmer
4,199,838	A	4/1980	Simonsson
4,209,254	A	6/1980	Reymond et al.
D258,901	S	4/1981	Keyworth
4,297,578	A	10/1981	Carter
4,305,234	A	12/1981	Pichelman
4,306,329	A	12/1981	Yokoi
4,309,758	A	1/1982	Halsall et al.
4,328,545	A	5/1982	Halsall et al.
4,367,403	A	1/1983	Miller
4,369,543	A	1/1983	Chen et al.
4,401,909	A	8/1983	Gorsek
4,416,033	A	11/1983	Specht
4,445,245	A	5/1984	Lu
4,465,370	A	8/1984	Yuasa et al.
4,477,998	A	10/1984	You
4,481,692	A	11/1984	Kurz
4,482,960	A	11/1984	Pryor
4,492,058	A	1/1985	Goldfarb et al.
4,513,469	A	4/1985	Godfrey et al.
D278,732	S	5/1985	Ohkado
4,518,437	A	5/1985	Sommer
4,534,637	A	8/1985	Suzuki et al.
4,556,313	A	12/1985	Miller et al.
4,575,211	A	3/1986	Matsumura et al.
4,580,311	A	4/1986	Kurz
4,601,082	A	7/1986	Kurz
4,618,213	A	10/1986	Chen
4,620,285	A	10/1986	Perdue
4,624,026	A	11/1986	Olson et al.
4,626,995	A	12/1986	Lofgren et al.
4,628,454	A	12/1986	Ito
4,638,445	A	1/1987	Mattaboni
4,644,156	A	2/1987	Takahashi et al.
4,649,504	A	3/1987	Krouglicof et al.
4,652,917	A	3/1987	Miller
4,654,492	A	3/1987	Koerner et al.
4,654,924	A	4/1987	Getz et al.
4,660,969	A	4/1987	Sorimachi et al.
4,662,854	A	5/1987	Fang
4,674,048	A	6/1987	Okumura
4,679,152	A	7/1987	Perdue
4,680,827	A	7/1987	Hummel
4,696,074	A	9/1987	Cavalli
D292,223	S	10/1987	Trumbull
4,700,301	A	10/1987	Dyke
4,700,427	A	10/1987	Knepper
4,703,820	A	11/1987	Reinaud
4,709,773	A	12/1987	Clement et al.
4,710,020	A	12/1987	Maddox et al.
4,712,740	A	12/1987	Duncan et al.
4,716,621	A	1/1988	Zoni
4,728,801	A	3/1988	O'Connor
4,733,343	A	3/1988	Yoneda et al.
4,733,430	A	3/1988	Westergren
4,733,431	A	3/1988	Martin
4,735,136	A	4/1988	Lee et al.
4,735,138	A	4/1988	Gawler et al.
4,748,336	A	5/1988	Fujie et al.
4,748,833	A	6/1988	Nagasawa
4,756,049	A	7/1988	Uehara
4,767,213	A	8/1988	Hummel
4,769,700	A	9/1988	Pryor
4,777,416	A	10/1988	George et al.
D298,766	S	11/1988	Tanno et al.
4,782,550	A	11/1988	Jacobs
4,796,198	A	1/1989	Boultinghouse et al.
4,806,751	A	2/1989	Abe et al.
4,811,228	A	3/1989	Hyyppa
4,813,906	A	3/1989	Matsuyama et al.
4,815,157	A	3/1989	Tsuchiya
4,817,000	A	3/1989	Eberhardt
4,818,875	A	4/1989	Weiner
4,829,442	A	5/1989	Kadonoff et al.
4,829,626	A	5/1989	Harkonen et al.
4,832,098	A	5/1989	Palinkas et al.
4,851,661	A	7/1989	Everett
4,854,000	A	8/1989	Takimoto
4,854,006	A	8/1989	Nishimura et al.
4,855,915	A	8/1989	Dallaire
4,857,912	A	8/1989	Everett et al.
4,858,132	A	8/1989	Holmquist
4,867,570	A	9/1989	Sorimachi et al.
4,880,474	A	11/1989	Koharagi et al.
4,887,415	A	12/1989	Martin
4,891,762	A	1/1990	Chotiros
4,893,025	A	1/1990	Lee
4,901,394	A	2/1990	Nakamura et al.
4,905,151	A	2/1990	Weiman et al.
4,909,972	A	3/1990	Britz
4,912,643	A	3/1990	Beirne
4,918,441	A	4/1990	Bohman
4,919,224	A	4/1990	Shyu et al.
4,919,489	A	4/1990	Kopsco
4,920,060	A	4/1990	Parrent et al.
4,920,605	A	5/1990	Takashima
4,933,864	A	6/1990	Evans et al.
4,937,912	A	7/1990	Kurz
4,953,253	A	9/1990	Fukuda et al.
4,954,962	A	9/1990	Evans et al.
4,955,714	A	9/1990	Stotler et al.
4,956,891	A	9/1990	Wulff
4,961,303	A	10/1990	McCarty et al.
4,961,304	A	10/1990	Ovsborn et al.
4,962,453	A	10/1990	Pong et al.
4,967,862	A	11/1990	Pong et al.

(56) **References Cited**

U.S. PATENT DOCUMENTS

4,971,591	A		11/1990	Raviv et al.
4,973,912	A		11/1990	Kaminski et al.
4,974,283	A		12/1990	Holsten et al.
4,977,618	A		12/1990	Allen
4,977,639	A		12/1990	Takahashi et al.
4,986,663	A		1/1991	Cecchi et al.
5,001,635	A		3/1991	Yasutomi et al.
5,002,145	A		3/1991	Wakaumi et al.
5,012,886	A		5/1991	Jonas et al.
5,018,240	A		5/1991	Holman
5,020,186	A		6/1991	Lessig et al.
5,022,812	A		6/1991	Coughlan et al.
5,023,788	A		6/1991	Kitazume et al.
5,024,529	A		6/1991	Svetkoff et al.
D318,500	S		7/1991	Malewicki et al.
5,032,775	A	*	7/1991	Mizuno et al. 701/25
5,033,151	A		7/1991	Kraft et al.
5,033,291	A		7/1991	Podoloff et al.
5,040,116	A		8/1991	Evans et al.
5,045,769	A		9/1991	Everett
5,049,802	A		9/1991	Mintus et al.
5,051,906	A		9/1991	Evans et al.
5,062,819	A		11/1991	Mallory
5,070,567	A		12/1991	Holland
5,084,934	A		2/1992	Lessig et al.
5,086,535	A		2/1992	Grossmeyer et al.
5,090,321	A		2/1992	Abouav
5,093,955	A		3/1992	Blehert et al.
5,094,311	A		3/1992	Akeel
5,098,262	A		3/1992	Wecker et al.
5,105,502	A		4/1992	Takashima
5,105,550	A		4/1992	Shenoha
5,109,566	A		5/1992	Kobayashi et al.
5,111,401	A		5/1992	Everett, Jr. et al.
5,115,538	A		5/1992	Cochran et al.
5,127,128	A		7/1992	Lee
5,136,675	A		8/1992	Hodson
5,136,750	A		8/1992	Takashima et al.
5,142,985	A		9/1992	Stearns et al.
5,144,471	A		9/1992	Takanashi et al.
5,144,714	A		9/1992	Mori et al.
5,144,715	A		9/1992	Matsuyo et al.
5,152,028	A		10/1992	Hirano
5,152,202	A		10/1992	Strauss
5,154,617	A		10/1992	Suman et al.
5,155,684	A		10/1992	Burke et al.
5,163,202	A		11/1992	Kawakami et al.
5,163,320	A		11/1992	Goshima et al.
5,164,579	A		11/1992	Pryor et al.
5,165,064	A		11/1992	Mattaboni
5,170,352	A		12/1992	McTamaney et al.
5,173,881	A		12/1992	Sindle
5,182,833	A		2/1993	Yamaguchi et al.
5,187,662	A		2/1993	Kamimura et al.
5,202,742	A		4/1993	Frank et al.
5,204,814	A		4/1993	Noonan et al.
5,206,500	A		4/1993	Decker et al.
5,208,521	A		5/1993	Aoyama
5,216,777	A		6/1993	Moro et al.
5,222,786	A		6/1993	Sovis et al.
5,227,985	A		7/1993	DeMenthon
5,233,682	A		8/1993	Abe et al.
5,239,720	A		8/1993	Wood et al.
5,251,358	A		10/1993	Moro et al.
5,261,139	A		11/1993	Lewis
5,276,618	A		1/1994	Everett
5,276,939	A		1/1994	Uenishi
5,277,064	A		1/1994	Knigga et al.
5,279,672	A		1/1994	Betker et al.
5,284,452	A		2/1994	Corona
5,284,522	A		2/1994	Kobayashi et al.
5,293,955	A		3/1994	Lee
D345,707	S		4/1994	Alister
5,303,448	A		4/1994	Hennessey et al.
5,307,271	A	*	4/1994	Everett et al. 701/24
5,307,273	A		4/1994	Oh et al.
5,309,592	A		5/1994	Hiratsuka
5,310,379	A		5/1994	Hippely et al.
5,315,227	A		5/1994	Pierson et al.
5,319,827	A		6/1994	Yang
5,319,828	A		6/1994	Waldhauser et al.
5,321,614	A	*	6/1994	Ashworth 701/26
5,323,483	A		6/1994	Baeg
5,324,948	A		6/1994	Dudar et al.
5,331,713	A		7/1994	Tipton
5,341,186	A		8/1994	Kato
5,341,540	A		8/1994	Soupert et al.
5,341,549	A		8/1994	Wirtz et al.
5,345,649	A		9/1994	Whitlow
5,352,901	A		10/1994	Poorman
5,353,224	A		10/1994	Lee et al.
5,363,305	A		11/1994	Cox et al.
5,363,935	A		11/1994	Schempf et al.
5,369,347	A		11/1994	Yoo
5,369,838	A		12/1994	Wood et al.
5,386,862	A		2/1995	Glover et al.
5,399,951	A		3/1995	Lavallee et al.
5,400,244	A		3/1995	Watanabe et al.
5,404,612	A		4/1995	Ishikawa
5,410,479	A		4/1995	Coker
5,435,405	A		7/1995	Schempf et al.
5,440,216	A		8/1995	Kim
5,442,358	A		8/1995	Keeler et al.
5,444,965	A		8/1995	Colens
5,446,356	A		8/1995	Kim
5,446,445	A		8/1995	Bloomfield et al.
5,451,135	A		9/1995	Schempf et al.
5,454,129	A		10/1995	Kell
5,455,982	A		10/1995	Armstrong et al.
5,465,525	A		11/1995	Mifune et al.
5,465,619	A		11/1995	Sotack et al.
5,467,273	A		11/1995	Faibish et al.
5,471,560	A		11/1995	Allard et al.
5,491,670	A		2/1996	Weber
5,497,529	A		3/1996	Boesi
5,498,948	A		3/1996	Bruni et al.
5,502,638	A		3/1996	Takenaka
5,505,072	A		4/1996	Oreper
5,507,067	A		4/1996	Hoekstra et al.
5,510,893	A		4/1996	Suzuki
5,511,147	A		4/1996	Abdel-Malek
5,515,572	A		5/1996	Hoekstra et al.
5,534,762	A		7/1996	Kim
5,535,476	A		7/1996	Kresse et al.
5,537,017	A		7/1996	Feiten et al.
5,537,711	A		7/1996	Tseng
5,539,953	A		7/1996	Kurz
5,542,146	A		8/1996	Hoekstra et al.
5,542,148	A		8/1996	Young
5,546,631	A		8/1996	Chambon
5,548,511	A		8/1996	Bancroft
5,551,119	A		9/1996	Wörwag
5,551,525	A		9/1996	Pack et al.
5,553,349	A		9/1996	Kilstrom et al.
5,555,587	A		9/1996	Guha
5,560,077	A		10/1996	Crotchett
5,568,589	A		10/1996	Hwang
D375,592	S		11/1996	Ljunggren
5,608,306	A		3/1997	Rybeck et al.
5,608,894	A		3/1997	Kawakami et al.
5,608,944	A		3/1997	Gordon
5,610,488	A		3/1997	Miyazawa
5,611,106	A		3/1997	Wulff
5,611,108	A		3/1997	Knowlton et al.
5,613,261	A		3/1997	Kawakami et al.
5,613,269	A		3/1997	Miwa
5,621,291	A		4/1997	Lee
5,622,236	A		4/1997	Azumi et al.
5,634,237	A		6/1997	Paranjpe
5,634,239	A		6/1997	Tuvin et al.
5,636,402	A		6/1997	Kubo et al.
5,642,299	A		6/1997	Hardin et al.
5,646,494	A		7/1997	Han
5,647,554	A		7/1997	Ikegami et al.

(56) **References Cited**

U.S. PATENT DOCUMENTS

5,650,702	A		7/1997	Azumi	
5,652,489	A		7/1997	Kawakami	
5,677,836	A	*	10/1997	Bauer	701/23
5,682,313	A		10/1997	Edlund et al.	
5,682,839	A		11/1997	Grimsley et al.	
5,696,675	A		12/1997	Nakamura et al.	
5,698,861	A		12/1997	Oh	
5,709,007	A		1/1998	Chiang	
5,710,506	A		1/1998	Broell et al.	
5,714,119	A		2/1998	Kawagoe et al.	
5,717,169	A		2/1998	Liang et al.	
5,717,484	A		2/1998	Hamaguchi et al.	
5,720,077	A		2/1998	Nakamura et al.	
5,732,401	A		3/1998	Conway	
5,735,017	A		4/1998	Barnes et al.	
5,735,959	A		4/1998	Kubo et al.	
5,742,975	A		4/1998	Knowlton et al.	
5,745,235	A		4/1998	Vercammen et al.	
5,752,871	A		5/1998	Tsuzuki	
5,756,904	A		5/1998	Oreper et al.	
5,761,762	A		6/1998	Kubo	
5,764,888	A		6/1998	Bolan et al.	
5,767,437	A		6/1998	Rogers	
5,767,960	A		6/1998	Orman	
5,770,936	A		6/1998	Hirai et al.	
5,777,596	A		7/1998	Herbert	
5,778,486	A		7/1998	Kim	
5,781,697	A		7/1998	Jeong	
5,781,960	A		7/1998	Kilstrom et al.	
5,784,755	A		7/1998	Karr et al.	
5,786,602	A		7/1998	Pryor et al.	
5,787,545	A		8/1998	Colens	
5,793,900	A		8/1998	Nourbakhsh et al.	
5,794,297	A		8/1998	Muta	
5,802,665	A		9/1998	Knowlton et al.	
5,812,267	A		9/1998	Everett et al.	
5,814,808	A		9/1998	Takada et al.	
5,815,880	A		10/1998	Nakanishi	
5,815,884	A		10/1998	Imamura et al.	
5,819,008	A		10/1998	Asama et al.	
5,819,360	A		10/1998	Fujii	
5,819,936	A		10/1998	Saveliev et al.	
5,820,821	A		10/1998	Kawagoe et al.	
5,821,730	A		10/1998	Drapkin	
5,825,981	A		10/1998	Matsuda	
5,828,770	A		10/1998	Leis et al.	
5,831,597	A		11/1998	West et al.	
5,836,045	A		11/1998	Anthony et al.	
5,839,156	A		11/1998	Park et al.	
5,839,532	A		11/1998	Yoshiji et al.	
5,841,259	A		11/1998	Kim et al.	
5,867,800	A		2/1999	Leif	
5,867,861	A		2/1999	Kasen et al.	
5,869,910	A		2/1999	Colens	
5,894,621	A		4/1999	Kubo	
5,896,611	A		4/1999	Haaga	
5,903,124	A		5/1999	Kawakami	
5,905,209	A		5/1999	Oreper	
5,907,886	A		6/1999	Buscher	
5,910,700	A		6/1999	Crotzer	
5,911,260	A		6/1999	Suzuki	
5,916,008	A		6/1999	Wong	
5,924,167	A		7/1999	Wright et al.	
5,926,909	A		7/1999	McGee	
5,933,102	A		8/1999	Miller et al.	
5,933,913	A		8/1999	Wright et al.	
5,935,179	A		8/1999	Kleiner et al.	
5,935,333	A		8/1999	Davis	
5,940,346	A		8/1999	Sadowsky et al.	
5,940,927	A		8/1999	Haegermarck et al.	
5,940,930	A		8/1999	Oh et al.	
5,942,869	A	*	8/1999	Katou et al.	318/568.12
5,943,730	A		8/1999	Boomgaarden	
5,943,733	A		8/1999	Tagliaferri	
5,943,933	A		8/1999	Evans et al.	
5,947,225	A		9/1999	Kawakami et al.	
5,950,408	A		9/1999	Schaedler	
5,959,423	A		9/1999	Nakanishi et al.	
5,968,281	A		10/1999	Wright et al.	
5,974,348	A		10/1999	Rocks	
5,974,365	A		10/1999	Mitchell	
5,983,448	A		11/1999	Wright et al.	
5,984,880	A		11/1999	Lander et al.	
5,987,383	A		11/1999	Keller et al.	
5,989,700	A		11/1999	Krivopal	
5,991,951	A		11/1999	Kubo et al.	
5,995,883	A		11/1999	Nishikado	
5,995,884	A	*	11/1999	Allen et al.	701/24
5,996,167	A		12/1999	Close	
5,998,953	A		12/1999	Nakamura et al.	
5,998,971	A		12/1999	Corbridge	
6,000,088	A		12/1999	Wright et al.	
6,009,358	A		12/1999	Angott et al.	
6,009,359	A	*	12/1999	El-Hakim et al.	701/28
6,012,618	A		1/2000	Matsuo et al.	
6,021,545	A		2/2000	Delgado et al.	
6,023,813	A		2/2000	Thatcher et al.	
6,023,814	A		2/2000	Imamura	
6,025,687	A		2/2000	Himeda et al.	
6,026,539	A		2/2000	Mouw et al.	
6,030,464	A		2/2000	Azevedo	
6,030,465	A		2/2000	Marcussen et al.	
6,032,327	A		3/2000	Oka et al.	
6,032,542	A		3/2000	Warnick et al.	
6,036,572	A		3/2000	Sze	
6,038,501	A		3/2000	Kawakami	
6,040,669	A		3/2000	Hog	
6,041,471	A		3/2000	Charky et al.	
6,041,472	A		3/2000	Kasen et al.	
6,046,800	A		4/2000	Ohtomo et al.	
6,049,620	A		4/2000	Dickinson et al.	
6,050,648	A		4/2000	Keleny	
6,052,821	A		4/2000	Chouly et al.	
6,055,042	A		4/2000	Sarangapani	
6,055,702	A		5/2000	Imamura et al.	
6,061,868	A		5/2000	Moritsch et al.	
6,065,182	A		5/2000	Wright et al.	
6,070,290	A		6/2000	Schwarze et al.	
6,073,432	A		6/2000	Schaedler	
6,076,025	A	*	6/2000	Ueno et al.	701/23
6,076,026	A		6/2000	Jambhekar et al.	
6,076,226	A		6/2000	Reed	
6,076,227	A		6/2000	Schallig et al.	
6,081,257	A		6/2000	Zeller	
6,088,020	A		7/2000	Mor	
6,094,775	A		8/2000	Behmer	
6,099,091	A		8/2000	Campbell	
6,101,670	A		8/2000	Song	
6,101,671	A		8/2000	Wright et al.	
6,108,031	A		8/2000	King et al.	
6,108,067	A		8/2000	Okamoto	
6,108,076	A		8/2000	Hanseder	
6,108,269	A		8/2000	Kabel	
6,108,597	A		8/2000	Kirchner et al.	
6,108,859	A		8/2000	Burgoon	
6,112,143	A		8/2000	Allen et al.	
6,112,996	A		9/2000	Matsuo	
6,119,057	A		9/2000	Kawagoe	
6,122,798	A		9/2000	Kobayashi et al.	
6,124,694	A		9/2000	Bancroft et al.	
6,125,498	A		10/2000	Roberts et al.	
6,131,237	A		10/2000	Kasper et al.	
6,138,063	A		10/2000	Himeda	
6,142,252	A		11/2000	Kinto et al.	
6,146,041	A		11/2000	Chen et al.	
6,146,278	A		11/2000	Kobayashi	
6,154,279	A		11/2000	Thayer	
6,154,694	A		11/2000	Aoki et al.	
6,160,479	A		12/2000	Ahlen et al.	
6,167,332	A		12/2000	Kurtzberg et al.	
6,167,587	B1		1/2001	Kasper et al.	
6,192,548	B1		2/2001	Huffman	
6,192,549	B1		2/2001	Kasen et al.	
6,202,243	B1		3/2001	Beaufoy et al.	

(56) **References Cited**

U.S. PATENT DOCUMENTS

6,216,307 B1 4/2001 Kaleta et al.
6,220,865 B1 4/2001 Macri et al.
6,226,830 B1 5/2001 Hendriks et al.
6,230,362 B1 5/2001 Kasper et al.
6,237,741 B1 5/2001 Guidetti
6,240,342 B1 5/2001 Fiegert et al.
6,243,913 B1 6/2001 Frank et al.
6,255,793 B1 7/2001 Peless et al.
6,259,979 B1 7/2001 Holmquist
6,261,379 B1 7/2001 Conrad et al.
6,263,539 B1 7/2001 Baig
6,263,989 B1 7/2001 Won
6,272,936 B1 8/2001 Oreper et al.
6,276,478 B1 8/2001 Hopkins et al.
6,278,918 B1 8/2001 Dickson et al.
6,279,196 B2 8/2001 Kasen et al.
6,282,526 B1 8/2001 Ganesh
6,283,034 B1 9/2001 Miles
6,285,778 B1 9/2001 Nakajima et al.
6,285,930 B1 9/2001 Dickson et al.
6,286,181 B1 9/2001 Kasper et al.
6,292,712 B1 * 9/2001 Bullen 700/245
6,300,737 B1 10/2001 Bergvall et al.
6,321,337 B1 11/2001 Reshef et al.
6,321,515 B1 11/2001 Colens
6,323,570 B1 11/2001 Nishimura et al.
6,324,714 B1 12/2001 Walz et al.
6,327,741 B1 12/2001 Reed
6,332,400 B1 12/2001 Meyer
6,339,735 B1 * 1/2002 Peless et al. 701/23
6,362,875 B1 3/2002 Burkley
6,370,453 B2 * 4/2002 Sommer 701/23
6,374,155 B1 4/2002 Wallach et al.
6,374,157 B1 4/2002 Takamura
6,381,802 B2 5/2002 Park
6,385,515 B1 5/2002 Dickson et al.
6,388,013 B1 5/2002 Saraf et al.
6,389,329 B1 5/2002 Colens
6,397,429 B1 6/2002 Legatt et al.
6,400,048 B1 6/2002 Nishimura et al.
6,401,294 B2 6/2002 Kasper
6,408,226 B1 6/2002 Byrne et al.
6,412,141 B2 7/2002 Kasper et al.
6,415,203 B1 7/2002 Inoue et al.
6,418,586 B2 7/2002 Fulghum
6,421,870 B1 7/2002 Basham et al.
6,427,285 B1 8/2002 Legatt et al.
6,430,471 B1 8/2002 Kintou et al.
6,431,296 B1 8/2002 Won
6,437,227 B1 8/2002 Theimer
6,437,465 B1 8/2002 Nishimura et al.
6,438,456 B1 8/2002 Feddema et al.
6,438,793 B1 8/2002 Miner et al.
6,442,476 B1 8/2002 Poropat
6,442,789 B1 9/2002 Legatt et al.
6,443,509 B1 9/2002 Levin et al.
6,444,003 B1 9/2002 Sutcliffe
6,446,302 B1 9/2002 Kasper et al.
6,454,036 B1 9/2002 Airey et al.
D464,091 S 10/2002 Christianson
6,457,206 B1 * 10/2002 Judson 15/320
6,459,955 B1 10/2002 Bartsch et al.
6,463,368 B1 10/2002 Feiten et al.
6,465,982 B1 10/2002 Bergvall et al.
6,473,167 B1 10/2002 Odell
6,480,762 B1 11/2002 Uchikubo et al.
6,481,515 B1 11/2002 Kirkpatrick et al.
6,482,252 B1 11/2002 Conrad et al.
6,490,539 B1 12/2002 Dickson et al.
6,491,127 B1 12/2002 Holmberg et al.
6,493,612 B1 12/2002 Bisset et al.
6,493,613 B2 12/2002 Peless et al.
6,496,754 B2 12/2002 Song et al.
6,496,755 B2 * 12/2002 Wallach et al. 700/245
6,502,657 B2 1/2003 Kerrebrock et al.
6,504,610 B1 1/2003 Bauer et al.
6,507,773 B2 1/2003 Parker et al.
6,519,808 B2 2/2003 Legatt et al.
6,525,509 B1 2/2003 Petersson et al.
D471,243 S 3/2003 Cioffi et al.
6,530,102 B1 3/2003 Pierce et al.
6,530,117 B2 3/2003 Peterson
6,532,404 B2 3/2003 Colens
6,535,793 B2 3/2003 Allard
6,540,424 B1 4/2003 Hall et al.
6,540,607 B2 4/2003 Mokris et al.
6,548,982 B1 4/2003 Papanikolopoulos et al.
6,553,612 B1 4/2003 Dyson et al.
6,556,722 B1 4/2003 Russell et al.
6,556,892 B2 4/2003 Kuroki et al.
6,557,104 B2 4/2003 Vu et al.
D474,312 S 5/2003 Stephens et al.
6,563,130 B2 5/2003 Dworkowski et al.
6,571,415 B2 6/2003 Gerber et al.
6,571,422 B1 6/2003 Gordon et al.
6,572,711 B2 6/2003 Sclafani et al.
6,574,536 B1 * 6/2003 Kawagoe et al. 701/23
6,580,246 B2 6/2003 Jacobs
6,584,376 B1 6/2003 Van Kommer
6,586,908 B2 7/2003 Petersson et al.
6,587,573 B1 7/2003 Stam et al.
6,590,222 B1 7/2003 Bisset et al.
6,594,551 B2 7/2003 McKinney et al.
6,594,844 B2 7/2003 Jones
6,597,076 B2 7/2003 Scheible et al.
D478,884 S 8/2003 Slipy et al.
6,601,265 B1 8/2003 Burlington
6,604,021 B2 8/2003 Imai et al.
6,604,022 B2 8/2003 Parker et al.
6,605,156 B1 8/2003 Clark et al.
6,609,269 B2 8/2003 Kasper
6,611,120 B2 8/2003 Song et al.
6,611,734 B2 8/2003 Parker et al.
6,611,738 B2 8/2003 Ruffner
6,615,108 B1 9/2003 Peless et al.
6,615,434 B1 9/2003 Davis et al.
6,615,885 B1 9/2003 Ohm
6,622,465 B2 9/2003 Jerome et al.
6,624,744 B1 9/2003 Wilson et al.
6,625,843 B2 9/2003 Kim et al.
6,629,028 B2 9/2003 Paromtchik et al.
6,633,150 B1 10/2003 Wallach et al.
6,637,546 B1 10/2003 Wang
6,639,659 B2 10/2003 Granger
6,658,325 B2 * 12/2003 Zweig 700/245
6,658,354 B2 12/2003 Lin
6,658,692 B2 12/2003 Lenkiewicz et al.
6,658,693 B1 12/2003 Reed
6,661,239 B1 12/2003 Ozick
6,662,889 B2 12/2003 De Fazio et al.
6,668,951 B2 12/2003 Won
6,670,817 B2 12/2003 Fournier et al.
6,671,592 B1 12/2003 Bisset et al.
6,671,925 B2 1/2004 Field et al.
6,677,938 B1 1/2004 Maynard
6,687,571 B1 2/2004 Byrne et al.
6,690,134 B1 2/2004 Jones et al.
6,690,993 B2 2/2004 Foulke et al.
6,697,147 B2 2/2004 Ko et al.
6,705,332 B2 3/2004 Field et al.
6,711,280 B2 3/2004 Stafsudd et al.
6,732,826 B2 * 5/2004 Song et al. 180/169
6,735,811 B2 5/2004 Field et al.
6,735,812 B2 5/2004 Hekman et al.
6,737,591 B1 5/2004 Lapstun et al.
6,741,054 B2 5/2004 Koselka et al.
6,741,364 B2 5/2004 Lange et al.
6,748,297 B2 6/2004 Song et al.
6,756,703 B2 6/2004 Chang
6,760,647 B2 7/2004 Nourbakhsh et al.
6,764,373 B1 7/2004 Osawa et al.
6,769,004 B2 7/2004 Barrett
6,774,596 B1 8/2004 Bisset
6,779,380 B1 8/2004 Nieuwkamp

(56) **References Cited**

U.S. PATENT DOCUMENTS

6,781,338 B2 8/2004 Jones et al.
6,809,490 B2 10/2004 Jones et al.
6,810,305 B2 10/2004 Kirkpatrick
6,810,350 B2 10/2004 Blakley
6,830,120 B1 * 12/2004 Yashima et al. 180/167
6,832,407 B2 12/2004 Salem et al.
6,836,701 B2 12/2004 McKee
6,841,963 B2 1/2005 Song et al.
6,845,297 B2 1/2005 Allard
6,848,146 B2 2/2005 Wright et al.
6,854,148 B1 2/2005 Rief et al.
6,856,811 B2 2/2005 Burdue et al.
6,859,010 B2 2/2005 Jeon et al.
6,859,682 B2 2/2005 Naka et al.
6,860,206 B1 3/2005 Rudakevych et al.
6,865,447 B2 3/2005 Lau et al.
6,870,792 B2 3/2005 Chiappetta
6,871,115 B2 3/2005 Huang et al.
6,883,201 B2 4/2005 Jones et al.
6,886,651 B1 5/2005 Slocum et al.
6,888,333 B2 5/2005 Laby
6,901,624 B2 6/2005 Mori et al.
6,906,702 B1 6/2005 Tanaka et al.
6,914,403 B2 7/2005 Tsurumi
6,917,854 B2 7/2005 Bayer
6,925,357 B2 8/2005 Wang et al.
6,925,679 B2 8/2005 Wallach et al.
6,929,548 B2 8/2005 Wang
D510,066 S 9/2005 Hickey et al.
6,938,298 B2 9/2005 Aasen
6,940,291 B1 9/2005 Ozick
6,941,199 B1 9/2005 Bottomley et al.
6,956,348 B2 10/2005 Landry et al.
6,957,712 B2 10/2005 Song et al.
6,960,986 B2 11/2005 Asama et al.
6,965,209 B2 11/2005 Jones et al.
6,965,211 B2 11/2005 Tsurumi
6,968,592 B2 11/2005 Takeuchi et al.
6,971,140 B2 12/2005 Kim
6,975,246 B1 12/2005 Trudeau
6,980,229 B1 12/2005 Ebersole
6,985,556 B2 1/2006 Shanmugavel et al.
6,993,954 B1 2/2006 George et al.
6,999,850 B2 2/2006 McDonald
7,013,527 B2 3/2006 Thomas et al.
7,024,278 B2 4/2006 Chiappetta et al.
7,024,280 B2 4/2006 Parker et al.
7,027,893 B2 4/2006 Perry et al.
7,030,768 B2 4/2006 Wanie
7,031,805 B2 4/2006 Lee et al.
7,032,469 B2 4/2006 Bailey
7,040,869 B2 5/2006 Beenker
7,041,029 B2 5/2006 Fulghum et al.
7,051,399 B2 5/2006 Field et al.
7,053,578 B2 5/2006 Diehl et al.
7,054,716 B2 5/2006 McKee et al.
7,055,210 B2 6/2006 Keppler et al.
7,057,120 B2 6/2006 Ma et al.
7,057,643 B2 6/2006 Iida et al.
7,059,012 B2 6/2006 Song et al.
7,065,430 B2 6/2006 Naka et al.
7,066,291 B2 6/2006 Martins et al.
7,069,124 B1 6/2006 Whittaker et al.
7,079,923 B2 7/2006 Abramson et al.
7,085,623 B2 8/2006 Siegers
7,085,624 B2 8/2006 Aldred et al.
7,113,847 B2 9/2006 Chmura et al.
7,133,746 B2 11/2006 Abramson et al.
7,142,198 B2 11/2006 Lee
7,148,458 B2 12/2006 Schell et al.
7,155,308 B2 12/2006 Jones
7,167,775 B2 1/2007 Abramson et al.
7,171,285 B2 1/2007 Kim et al.
7,173,391 B2 2/2007 Jones et al.
7,174,238 B1 2/2007 Zweig
7,188,000 B2 3/2007 Chiappetta et al.
7,193,384 B1 3/2007 Norman et al.
7,196,487 B2 3/2007 Jones et al.
7,201,786 B2 4/2007 Wegelin et al.
7,206,677 B2 4/2007 Hulden
7,211,980 B1 5/2007 Bruemmer et al.
7,225,500 B2 6/2007 Diehl et al.
7,246,405 B2 7/2007 Yan
7,248,951 B2 7/2007 Hulden
7,275,280 B2 10/2007 Haegermarck et al.
7,283,892 B1 10/2007 Boillot et al.
7,288,912 B2 10/2007 Landry et al.
7,318,248 B1 1/2008 Yan et al.
7,320,149 B1 1/2008 Huffman et al.
7,321,807 B2 1/2008 Laski
7,324,870 B2 1/2008 Lee
7,328,196 B2 2/2008 Peters
7,332,890 B2 2/2008 Cohen et al.
7,346,428 B1 3/2008 Huffman et al.
7,352,153 B2 4/2008 Yan
7,359,766 B2 4/2008 Jeon et al.
7,360,277 B2 4/2008 Moshenrose et al.
7,363,108 B2 4/2008 Noda et al.
7,388,879 B2 6/2008 Sabe et al.
7,389,156 B2 6/2008 Ziegler et al.
7,389,166 B2 6/2008 Harwig et al.
7,408,157 B2 8/2008 Yan
7,418,762 B2 9/2008 Arai et al.
7,430,455 B2 9/2008 Casey et al.
7,430,462 B2 9/2008 Chiu et al.
7,441,298 B2 10/2008 Svendsen et al.
7,444,206 B2 10/2008 Abramson et al.
7,448,113 B2 11/2008 Jones et al.
7,459,871 B2 12/2008 Landry et al.
7,467,026 B2 12/2008 Sakagami et al.
7,474,941 B2 1/2009 Kim et al.
7,503,096 B2 3/2009 Lin
7,515,991 B2 4/2009 Egawa et al.
7,539,557 B2 5/2009 Yamauchi
7,555,363 B2 6/2009 Augenbraun et al.
7,557,703 B2 7/2009 Yamada et al.
7,568,259 B2 8/2009 Yan
7,571,511 B2 8/2009 Jones et al.
7,578,020 B2 8/2009 Jaworski et al.
7,600,521 B2 10/2009 Woo
7,603,744 B2 10/2009 Reindle
7,611,583 B2 11/2009 Buckley et al.
7,617,557 B2 11/2009 Reindle
7,620,476 B2 11/2009 Morse et al.
7,636,928 B2 12/2009 Uno
7,636,982 B2 12/2009 Jones et al.
7,647,144 B2 1/2010 Haegermarck
7,650,666 B2 1/2010 Jang
7,660,650 B2 2/2010 Kawagoe et al.
7,663,333 B2 2/2010 Jones et al.
7,693,605 B2 4/2010 Park
7,706,917 B1 4/2010 Chiappetta et al.
7,761,954 B2 7/2010 Ziegler et al.
7,765,635 B2 8/2010 Park
7,784,147 B2 8/2010 Burkholder et al.
7,801,645 B2 9/2010 Taylor et al.
7,805,220 B2 * 9/2010 Taylor et al. 700/253
7,809,944 B2 10/2010 Kawamoto
7,832,048 B2 11/2010 Harwig et al.
7,849,555 B2 12/2010 Hahm et al.
7,853,645 B2 12/2010 Brown et al.
7,860,680 B2 12/2010 Arms et al.
7,920,941 B2 4/2011 Park et al.
7,937,800 B2 5/2011 Yan
7,957,836 B2 6/2011 Myeong et al.
8,087,117 B2 1/2012 Kapoor et al.
8,396,599 B2 * 3/2013 Matsuo et al. 700/264
2001/0004719 A1 6/2001 Sommer
2001/0013929 A1 8/2001 Torsten
2001/0020200 A1 9/2001 Das et al.
2001/0025183 A1 9/2001 Shahidi
2001/0037163 A1 11/2001 Allard
2001/0043509 A1 11/2001 Green et al.
2001/0045883 A1 11/2001 Holdaway et al.

(56) **References Cited**

U.S. PATENT DOCUMENTS

2001/0047231 A1 11/2001 Peless et al.
2001/0047895 A1 12/2001 De Fazio et al.
2002/0011367 A1 1/2002 Kolesnik
2002/0011813 A1 1/2002 Koselka et al.
2002/0016649 A1 2/2002 Jones
2002/0021219 A1 2/2002 Edwards
2002/0027652 A1 3/2002 Paromtchik et al.
2002/0036779 A1 3/2002 Kiyoi et al.
2002/0060542 A1* 5/2002 Song et al. 318/568.12
2002/0081937 A1 6/2002 Yamada et al.
2002/0095239 A1 7/2002 Wallach et al.
2002/0097400 A1 7/2002 Jung et al.
2002/0104963 A1 8/2002 Mancevski
2002/0108209 A1 8/2002 Peterson
2002/0112742 A1 8/2002 Bredo et al.
2002/0113973 A1 8/2002 Ge
2002/0116089 A1 8/2002 Kirkpatrick
2002/0120364 A1 8/2002 Colens
2002/0124343 A1 9/2002 Reed
2002/0153185 A1 10/2002 Song et al.
2002/0156556 A1 10/2002 Ruffner
2002/0159051 A1 10/2002 Guo
2002/0166193 A1 11/2002 Kasper
2002/0169521 A1 11/2002 Goodman et al.
2002/0173877 A1 11/2002 Zweig
2002/0189871 A1 12/2002 Won
2003/0009259 A1 1/2003 Hattori et al.
2003/0015232 A1 1/2003 Nguyen
2003/0019071 A1 1/2003 Field et al.
2003/0023356 A1 1/2003 Keable
2003/0024986 A1 2/2003 Mazz et al.
2003/0025472 A1 2/2003 Jones et al.
2003/0028286 A1 2/2003 Glenn et al.
2003/0030399 A1 2/2003 Jacobs
2003/0058262 A1 3/2003 Sato et al.
2003/0060928 A1 3/2003 Abramson et al.
2003/0067451 A1 4/2003 Tagg et al.
2003/0090522 A1* 5/2003 Verhaar 345/772
2003/0097875 A1 5/2003 Lentz et al.
2003/0120389 A1* 6/2003 Abramson et al. 700/245
2003/0124312 A1 7/2003 Autumn
2003/0126352 A1 7/2003 Barrett
2003/0137268 A1 7/2003 Papanikolopoulos et al.
2003/0146384 A1 8/2003 Logsdon et al.
2003/0159232 A1 8/2003 Hekman et al.
2003/0168081 A1 9/2003 Lee et al.
2003/0175138 A1 9/2003 Beenker
2003/0192144 A1 10/2003 Song et al.
2003/0193657 A1 10/2003 Uomori et al.
2003/0216834 A1 11/2003 Allard
2003/0221114 A1 11/2003 Hino et al.
2003/0229421 A1 12/2003 Chmura et al.
2003/0229474 A1 12/2003 Suzuki et al.
2003/0233171 A1 12/2003 Heiligensetzer
2003/0233177 A1 12/2003 Johnson et al.
2003/0233870 A1 12/2003 Mancevski
2003/0233930 A1 12/2003 Ozick
2004/0016077 A1 1/2004 Song et al.
2004/0020000 A1 2/2004 Jones
2004/0030448 A1 2/2004 Solomon
2004/0030449 A1 2/2004 Solomon
2004/0030450 A1 2/2004 Solomon
2004/0030451 A1 2/2004 Solomon
2004/0030570 A1 2/2004 Solomon
2004/0030571 A1 2/2004 Solomon
2004/0031113 A1 2/2004 Wosewick et al.
2004/0049877 A1 3/2004 Jones et al.
2004/0055163 A1 3/2004 McCambridge et al.
2004/0068351 A1 4/2004 Solomon
2004/0068415 A1 4/2004 Solomon
2004/0068416 A1 4/2004 Solomon
2004/0074038 A1 4/2004 Im et al.
2004/0074044 A1 4/2004 Diehl et al.
2004/0076324 A1 4/2004 Burl et al.
2004/0083570 A1 5/2004 Song et al.
2004/0085037 A1 5/2004 Jones et al.
2004/0088079 A1 5/2004 Lavarec et al.
2004/0093122 A1 5/2004 Galibraith
2004/0098167 A1 5/2004 Yi et al.
2004/0111184 A1 6/2004 Chiappetta et al.
2004/0111821 A1 6/2004 Lenkiewicz et al.
2004/0113777 A1 6/2004 Matsuhira et al.
2004/0117064 A1 6/2004 McDonald
2004/0117846 A1 6/2004 Karaoguz et al.
2004/0118998 A1 6/2004 Wingett et al.
2004/0128028 A1 7/2004 Miyamoto et al.
2004/0133316 A1 7/2004 Dean
2004/0134336 A1 7/2004 Solomon
2004/0134337 A1 7/2004 Solomon
2004/0143919 A1 7/2004 Wilder
2004/0148419 A1 7/2004 Chen et al.
2004/0148731 A1 8/2004 Damman et al.
2004/0153212 A1 8/2004 Profio et al.
2004/0156541 A1 8/2004 Jeon et al.
2004/0158357 A1 8/2004 Lee et al.
2004/0181706 A1 9/2004 Chen et al.
2004/0187249 A1 9/2004 Jones et al.
2004/0187457 A1 9/2004 Colens
2004/0196451 A1 10/2004 Aoyama
2004/0200505 A1 10/2004 Taylor et al.
2004/0201361 A1 10/2004 Koh et al.
2004/0204792 A1* 10/2004 Taylor et al. 700/245
2004/0204804 A1 10/2004 Lee et al.
2004/0210345 A1 10/2004 Noda et al.
2004/0210347 A1 10/2004 Sawada et al.
2004/0211444 A1* 10/2004 Taylor et al. 134/18
2004/0220707 A1* 11/2004 Pallister 701/24
2004/0221790 A1 11/2004 Sinclair et al.
2004/0236468 A1* 11/2004 Taylor et al. 700/245
2004/0244138 A1 12/2004 Taylor et al.
2004/0255425 A1 12/2004 Arai et al.
2005/0000543 A1* 1/2005 Taylor et al. 134/18
2005/0010330 A1 1/2005 Abramson et al.
2005/0010331 A1 1/2005 Taylor et al.
2005/0015920 A1 1/2005 Kim et al.
2005/0021181 A1 1/2005 Kim et al.
2005/0028316 A1 2/2005 Thomas et al.
2005/0053912 A1 3/2005 Roth et al.
2005/0055796 A1 3/2005 Wright et al.
2005/0067994 A1 3/2005 Jones et al.
2005/0081782 A1 4/2005 Buckley et al.
2005/0085947 A1 4/2005 Aldred et al.
2005/0091782 A1 5/2005 Gordon et al.
2005/0091786 A1 5/2005 Wright et al.
2005/0137749 A1 6/2005 Jeon et al.
2005/0144751 A1 7/2005 Kegg et al.
2005/0150074 A1 7/2005 Diehl et al.
2005/0150519 A1 7/2005 Keppler et al.
2005/0154795 A1 7/2005 Kuz et al.
2005/0156562 A1 7/2005 Cohen et al.
2005/0162119 A1 7/2005 Landry et al.
2005/0163119 A1 7/2005 Ito et al.
2005/0165508 A1 7/2005 Kanda et al.
2005/0166354 A1 8/2005 Uehigashi
2005/0166355 A1 8/2005 Tani
2005/0171636 A1* 8/2005 Tani 700/245
2005/0172445 A1 8/2005 Diehl et al.
2005/0183229 A1 8/2005 Uehigashi
2005/0183230 A1 8/2005 Uehigashi
2005/0187678 A1 8/2005 Myeong et al.
2005/0192707 A1 9/2005 Park et al.
2005/0204505 A1* 9/2005 Kashiwagi 15/319
2005/0204717 A1 9/2005 Colens
2005/0209736 A1 9/2005 Kawagoe
2005/0211880 A1 9/2005 Schell et al.
2005/0212929 A1 9/2005 Schell et al.
2005/0213082 A1 9/2005 DiBernardo et al.
2005/0213109 A1 9/2005 Schell et al.
2005/0217042 A1 10/2005 Reindle
2005/0218852 A1 10/2005 Landry et al.
2005/0222933 A1 10/2005 Wesby
2005/0229340 A1 10/2005 Sawalski et al.
2005/0229355 A1 10/2005 Crouch et al.
2005/0235451 A1 10/2005 Yan

(56) **References Cited**

U.S. PATENT DOCUMENTS

2005/0251292	A1	11/2005	Casey et al.	
2005/0255425	A1	11/2005	Pierson	
2005/0258154	A1	11/2005	Blankenship et al.	
2005/0273967	A1	12/2005	Taylor et al.	
2005/0288819	A1	12/2005	De Guzman	
2006/0000050	A1	1/2006	Cipolla et al.	
2006/0009879	A1	1/2006	Lynch et al.	
2006/0010638	A1	1/2006	Shimizu et al.	
2006/0020369	A1	1/2006	Taylor et al.	
2006/0020370	A1	1/2006	Abramson	
2006/0021168	A1	2/2006	Nishikawa	
2006/0025134	A1	2/2006	Cho et al.	
2006/0037170	A1	2/2006	Shimizu	
2006/0042042	A1	3/2006	Mertes et al.	
2006/0044546	A1	3/2006	Lewin et al.	
2006/0060216	A1	3/2006	Woo	
2006/0061657	A1	3/2006	Rew et al.	
2006/0064828	A1	3/2006	Stein et al.	
2006/0087273	A1	4/2006	Ko et al.	
2006/0089765	A1	4/2006	Pack et al.	
2006/0100741	A1	5/2006	Jung	
2006/0107894	A1	5/2006	Buckley et al.	
2006/0119839	A1	6/2006	Bertin et al.	
2006/0143295	A1	6/2006	Costa-Requena et al.	
2006/0146776	A1	7/2006	Kim	
2006/0150361	A1	7/2006	Aldred et al.	
2006/0184293	A1	8/2006	Konandreas et al.	
2006/0185690	A1	8/2006	Song et al.	
2006/0190133	A1	8/2006	Konandreas et al.	
2006/0190134	A1	8/2006	Ziegler et al.	
2006/0190146	A1	8/2006	Morse et al.	
2006/0196003	A1	9/2006	Song et al.	
2006/0200281	A1	9/2006	Ziegler et al.	
2006/0220900	A1	10/2006	Ceskutti et al.	
2006/0229774	A1	10/2006	Park et al.	
2006/0259194	A1	11/2006	Chiu	
2006/0259494	A1	11/2006	Watson et al.	
2006/0278161	A1	12/2006	Burkholder et al.	
2006/0288519	A1	12/2006	Jaworski et al.	
2006/0293787	A1	12/2006	Kanda et al.	
2006/0293788	A1*	12/2006	Pogodin	700/245
2006/0293808	A1	12/2006	Qian	
2007/0006404	A1	1/2007	Cheng et al.	
2007/0016328	A1	1/2007	Ziegler et al.	
2007/0017061	A1	1/2007	Yan	
2007/0028574	A1	2/2007	Yan	
2007/0032904	A1	2/2007	Kawagoe et al.	
2007/0042716	A1	2/2007	Goodall et al.	
2007/0043459	A1	2/2007	Abbott et al.	
2007/0061041	A1	3/2007	Zweig	
2007/0061043	A1	3/2007	Ermakov et al.	
2007/0114975	A1	5/2007	Cohen et al.	
2007/0142964	A1	6/2007	Abramson	
2007/0150096	A1	6/2007	Yeh et al.	
2007/0156286	A1	7/2007	Yamauchi	
2007/0157415	A1	7/2007	Lee et al.	
2007/0157420	A1	7/2007	Lee et al.	
2007/0179670	A1	8/2007	Chiappetta et al.	
2007/0226949	A1	10/2007	Hahm et al.	
2007/0234492	A1	10/2007	Svendsen et al.	
2007/0244610	A1	10/2007	Ozick et al.	
2007/0245511	A1	10/2007	Hahm et al.	
2007/0250212	A1	10/2007	Halloran et al.	
2007/0261193	A1	11/2007	Gordon et al.	
2007/0266508	A1	11/2007	Jones et al.	
2008/0007203	A1	1/2008	Cohen et al.	
2008/0039974	A1	2/2008	Sandin et al.	
2008/0052846	A1	3/2008	Kapoor et al.	
2008/0091304	A1	4/2008	Ozick et al.	
2008/0109126	A1	5/2008	Sandin et al.	
2008/0134458	A1	6/2008	Ziegler et al.	
2008/0140255	A1	6/2008	Ziegler et al.	
2008/0155768	A1	7/2008	Ziegler et al.	
2008/0184518	A1	8/2008	Taylor et al.	
2008/0266748	A1	10/2008	Lee	
2008/0276407	A1	11/2008	Schnittman et al.	
2008/0281470	A1	11/2008	Gilbert et al.	
2008/0282494	A1	11/2008	Won et al.	
2008/0294288	A1	11/2008	Yamauchi	
2008/0302586	A1	12/2008	Yan	
2008/0307590	A1	12/2008	Jones et al.	
2009/0007366	A1	1/2009	Svendsen et al.	
2009/0038089	A1	2/2009	Landry et al.	
2009/0048727	A1	2/2009	Hong et al.	
2009/0049640	A1	2/2009	Lee et al.	
2009/0055022	A1	2/2009	Casey et al.	
2009/0102296	A1	4/2009	Greene et al.	
2009/0292393	A1	11/2009	Casey et al.	
2010/0006028	A1	1/2010	Buckley et al.	
2010/0011529	A1	1/2010	Won et al.	
2010/0049365	A1	2/2010	Jones et al.	
2010/0063628	A1	3/2010	Landry et al.	
2010/0082193	A1	4/2010	Chiappetta	
2010/0107355	A1	5/2010	Won et al.	
2010/0257690	A1	10/2010	Jones et al.	
2010/0257691	A1	10/2010	Jones et al.	
2010/0263158	A1	10/2010	Jones et al.	
2010/0268384	A1	10/2010	Jones et al.	
2010/0293742	A1	11/2010	Chung et al.	
2010/0312429	A1	12/2010	Jones et al.	

FOREIGN PATENT DOCUMENTS

DE	3536907	C2	2/1989
DE	3404202	C2	12/1992
DE	199311014	U1	10/1993
DE	4338841	A1	5/1995
DE	4414683	A1	10/1995
DE	19849978		2/2001
DE	102004038074		6/2005
DE	10357636		7/2005
DE	102004041021	B3	8/2005
DE	102005046813	A1	4/2007
DK	338988	A	12/1988
EP	0265542	A1	5/1988
EP	0281085	A2	9/1988
EP	0286328	A1	10/1988
EP	0294101	A2	12/1988
EP	0352045	A2	1/1990
EP	0433697	A2	6/1991
EP	0437024	A1	7/1991
EP	0554978	A2	8/1993
EP	0615719	A1	9/1994
EP	0792726	A1	9/1997
EP	0930040	A2	7/1999
EP	0845237	B1	4/2000
EP	0861629	B1	9/2001
EP	1228734	A2164	8/2002
EP	1380245	A1	1/2004
EP	1380246	A2	1/2004
EP	1018315	B1	11/2004
EP	1553472	A1	7/2005
EP	1557730	A1	7/2005
EP	1642522	A2	4/2006
EP	1836941	A2	9/2007
ES	2238196	A1	8/2005
FR	722755		3/1932
FR	2601443	A1	1/1988
FR	2828589	A1	2/2003
GB	702426		1/1954
GB	2128842	A	5/1984
GB	2225221	A	5/1990
GB	2267360	A	12/1993
GB	2283838	A	5/1995
GB	2284957	A	6/1995
GB	2300082	A	10/1996
GB	2344747	A	6/2000
GB	2404330	A	2/2005
GB	2417354	A	2/2006
JP	53021869		2/1978
JP	53110257	A2	9/1978
JP	57064217		4/1982
JP	59005315		1/1984
JP	59033511	U	3/1984

(56) **References Cited**

FOREIGN PATENT DOCUMENTS

JP	59094005		5/1984
JP	59099308		6/1984
JP	59112311		6/1984
JP	59120124	A	7/1984
JP	59131668	U	9/1984
JP	59164973		9/1984
JP	59184917	A	10/1984
JP	2283343	A2	11/1984
JP	59212924		12/1984
JP	59226909		12/1984
JP	60089213	A	5/1985
JP	60211510	A	10/1985
JP	60259895		12/1985
JP	61023221		1/1986
JP	61097712	A	5/1986
JP	61160366		7/1986
JP	62070709		4/1987
JP	62074018	A	4/1987
JP	62120510	A	6/1987
JP	62154008		7/1987
JP	62164431		7/1987
JP	62263507	A	11/1987
JP	62263508	A	11/1987
JP	62189057	U	12/1987
JP	63079623	A	4/1988
JP	63158032		7/1988
JP	63203483	A	8/1988
JP	63241610	A	10/1988
JP	1118752		8/1989
JP	2-6312	U	1/1990
JP	3051023	A	3/1991
JP	4019586		1/1992
JP	4074285	A	3/1992
JP	4084921	A	3/1992
JP	5023269	A	2/1993
JP	5042076	A	2/1993
JP	5046246		2/1993
JP	5091604	A	4/1993
JP	5095879	A	4/1993
JP	5150827	A	6/1993
JP	5150829	A	6/1993
JP	5054620	U	7/1993
JP	5040519	Y2	10/1993
JP	05257527	A	10/1993
JP	5257533		10/1993
JP	05285861	A	11/1993
JP	5302836	A	11/1993
JP	5312514	A	11/1993
JP	05046239	Y2	12/1993
JP	5341904	A	12/1993
JP	6003251	U	1/1994
JP	6038912		2/1994
JP	6105781	A	4/1994
JP	6137828	A	5/1994
JP	6154143	A	6/1994
JP	6293095	A	10/1994
JP	06327 598	A	11/1994
JP	7047046	A	2/1995
JP	07129239	A	5/1995
JP	7059702	B	6/1995
JP	07222705	A2	8/1995
JP	7270518	A	10/1995
JP	7313417	A	12/1995
JP	8000393	A	1/1996
JP	8016776	A	1/1996
JP	8084696	A	4/1996
JP	8089449	A	4/1996
JP	08089451	A	4/1996
JP	8123548	A	5/1996
JP	8152916	A	6/1996
JP	8263137	A	10/1996
JP	8335112	A	12/1996
JP	8339297	A	12/1996
JP	943901		2/1997
JP	9044240	A	2/1997
JP	9066855	A	3/1997
JP	9145309	A	6/1997
JP	09160644	A	6/1997
JP	09179625	A	7/1997
JP	09185410		7/1997
JP	9192069	A	7/1997
JP	2555263	Y2	8/1997
JP	9204223	A	8/1997
JP	09206258	A	8/1997
JP	09233712	A	9/1997
JP	9265319	A	10/1997
JP	9269807	A	10/1997
JP	9269810	A	10/1997
JP	9319431	A1	12/1997
JP	9319432	A	12/1997
JP	9319434	A	12/1997
JP	9325812	A	12/1997
JP	10055215	A	2/1998
JP	10117973	A	5/1998
JP	10118963	A	5/1998
JP	10165738	A	6/1998
JP	10177414	A	6/1998
JP	10295595	A	11/1998
JP	10314088		12/1998
JP	11015941	A	1/1999
JP	11102220	A	4/1999
JP	11162454	A	6/1999
JP	11174145	A	7/1999
JP	11175149	A	7/1999
JP	11178765	A	7/1999
JP	114008764	A	7/1999
JP	11212642	A	8/1999
JP	11213157	A	8/1999
JP	11282532	A	10/1999
JP	11282533	A	10/1999
JP	11295412	A	10/1999
JP	2000047728		2/2000
JP	2000056006	A	2/2000
JP	2000056831	A	2/2000
JP	2000060782	A	2/2000
JP	2000066722	A	3/2000
JP	2000075925	A	3/2000
JP	2000102499	A	4/2000
JP	2000275321		10/2000
JP	2000279353	A	10/2000
JP	2000353014	A	12/2000
JP	2001022443	A	1/2001
JP	2001067588		3/2001
JP	2001087182		4/2001
JP	2001121455		5/2001
JP	2001125641		5/2001
JP	2001508572	A	6/2001
JP	2001197008	A	7/2001
JP	3197758	B2	8/2001
JP	3201903	B2	8/2001
JP	2001216482	A	8/2001
JP	2001258807		9/2001
JP	2001265437	A	9/2001
JP	2001275908	A	10/2001
JP	2001289939		10/2001
JP	2001306170	A	11/2001
JP	2002073170	A	3/2002
JP	2002078650	A	3/2002
JP	2002204768	A	7/2002
JP	2002204769	A	7/2002
JP	2002247510	A	8/2002
JP	2002532180	A	10/2002
JP	2002323925		11/2002
JP	2002333920	A	11/2002
JP	2002355206		12/2002
JP	2002360471	A	12/2002
JP	2002360482	A	12/2002
JP	2002366227		12/2002
JP	2002369778		12/2002
JP	2003005296	A	1/2003
JP	2003010076	A	1/2003
JP	2003010088	A	1/2003
JP	2003028528	A	1/2003
JP	2003036116	A	2/2003

(56) **References Cited**

FOREIGN PATENT DOCUMENTS

JP	2003038401	A	2/2003
JP	2003038402	A	2/2003
JP	2003047579		2/2003
JP	2003061882	A	3/2003
JP	2003084994		3/2003
JP	2003167628	A	6/2003
JP	2003180586	A	7/2003
JP	2003180587	A	7/2003
JP	2003186539	A	7/2003
JP	2003190064	A	7/2003
JP	2003241836	A	8/2003
JP	2003262520	A	9/2003
JP	2003304992	A	10/2003
JP	2003310509	A	11/2003
JP	2003330543	A	11/2003
JP	2004123040	A	4/2004
JP	2004148021	A	5/2004
JP	2004160102	A	6/2004
JP	2004166968	A	6/2004
JP	2004198330	A	7/2004
JP	2004219185		8/2004
JP	2004351234	A	12/2004
JP	2005118354	A	5/2005
JP	2005211360	A	8/2005
JP	2005224265	A	8/2005
JP	2005230032	A	9/2005
JP	2005245916	A	9/2005
JP	2005352707	A	12/2005
JP	2006043071	A	2/2006
JP	2006155274	A	6/2006
JP	2006164223	A	6/2006
JP	2006227673	A	8/2006
JP	2006247467	A	9/2006
JP	2006260161	A	9/2006
JP	2006293662	A	10/2006
JP	2006296697	A	11/2006
JP	2007034866	A	2/2007
JP	2007213180	A	8/2007
JP	2009015611	A	1/2009
JP	2010198552	A	9/2010
WO	9526512	A1	10/1995
WO	9530887	A1	11/1995
WO	9617258	A1	6/1996
WO	9715224	A1	5/1997
WO	9740734	A1	11/1997
WO	9741451	A1	11/1997
WO	9853456	A1	11/1998
WO	9905580	A2	2/1999
WO	9916078	A1	4/1999
WO	9938056	A1	7/1999
WO	9938237	A1	7/1999
WO	9943250	A1	9/1999
WO	0038026	A1	6/2000
WO	0038028	A1	6/2000
WO	0038029	A1	6/2000
WO	0004430	A1	10/2000
WO	0078410	A1	12/2000
WO	0106904	A1	2/2001
WO	0106905	A1	2/2001
WO	0180703	A1	11/2001
WO	0191623	A2	12/2001
WO	0224292	A1	3/2002
WO	0239864	A1	5/2002
WO	0239868	A1	5/2002
WO	02058527	A1	8/2002
WO	02062194	A1	8/2002
WO	02067744	A1	9/2002
WO	02067745	A1	9/2002
WO	02067752	A1	9/2002
WO	02069774	A1	9/2002
WO	02069775	A2	9/2002
WO	02071175	A1	9/2002
WO	02074150	A1	9/2002
WO	02075350	A1	9/2002
WO	02075356	A1	9/2002
WO	02075469	A1	9/2002
WO	02075470	A1	9/2002
WO	02081074	A1	10/2002
WO	02101477	A2	12/2002
WO	03015220	A1	2/2003
WO	03024292	A2	3/2003
WO	03040546	A1	5/2003
WO	03040845	A1	5/2003
WO	03040846	A1	5/2003
WO	03062850	A2	7/2003
WO	03062852	A1	7/2003
WO	2004004533	A1	1/2004
WO	2004004534	A1	1/2004
WO	2004006034	A2	1/2004
WO	2004025947	A2	3/2004
WO	2004058028	A2	7/2004
WO	2004059409	A1	7/2004
WO	2005006935	A1	1/2005
WO	2005037496	A1	4/2005
WO	2005055795	A1	6/2005
WO	2005055796	A2	6/2005
WO	2005076545	A1	8/2005
WO	2005077243	A1	8/2005
WO	2005077244	A1	8/2005
WO	2005081074	A1	9/2005
WO	2005083541	A1	9/2005
WO	2005098475	A1	10/2005
WO	2005098476	A1	10/2005
WO	2006046400	A1	5/2006
WO	2006061133	A1	6/2006
WO	2006068403	A1	6/2006
WO	2006073248	A1	7/2006
WO	2006089307	A2	8/2006
WO	2007028049	A2	3/2007
WO	2007036490	A2	4/2007
WO	2007065033	A2	6/2007
WO	2007137234	A2	11/2007

OTHER PUBLICATIONS

Andersen et al., "Landmark based navigation strategies," SPIE Conference on Mobile Robots XIII, SPIE vol. 3525, pp. 170-181, Jan. 8, 1999.

Ascii, Mar. 25, 2002, http://ascii.jp/elem/000/000/330/330024/, accessed Nov. 2011, 15 pages (with English translation).

Barker, "Navigation by the Stars—Ben Barker 4th Year Project," Nov. 2004, 20 pages.

Becker et al., "Reliable Navigation Using Landmarks," IEEE International Conference on Robotics and Automation, 0-7803-1965-6, pp. 401-406, 1995.

Benayad-Cherif et al., "Mobile Robot Navigation Sensors," SPIE vol. 1831 Mobile Robots, VII, pp. 378-387, 1992.

Betke et al. "Mobile robot localization using landmarks," Proceedings of the IEEE/RSJ/GI International Conference on Intelligent Robots and Systems '94 Advanced Robotic Systems and the Real World' (IROS '94), Accessed via IEEE Xplore, 1994, 8 pages.

Bison et al., "Using a structured beacon for cooperative position estimation," *Robotics and Autonomous Systems*, 29(1):33-40, Oct. 1999.

Blaasvaer et al., "AMOR—An Autonomous Mobile Robot Navigation System," Proceedings of the IEEE International Conference on Systems, Man, and Cybernetics, pp. 2266-2271, 1994.

Borges et al., "Optimal Mobile Robot Pose Estimation Using Geometrical Maps," IEEE Transactions on Robotics and Automation, 18(1): 87-94, Feb. 2002.

Braunstingl et al., "Fuzzy Logic Wall Following of a Mobile Robot Based on the Concept of General Perception," ICAR '95, 7th International Conference on Advanced Robotics, Sant Feliu De Guixols, Spain, pp. 367-376, Sep. 1995.

Bulusu et al., "Self Configuring Localization systems: Design and Experimental Evaluation,"*ACM Transactions on Embedded Computing Systems*, 3(1):24-60, 2003.

Caccia et al., "Bottom-Following for Remotely Operated Vehicles,"5th IFAC Conference, Alaborg, Denmark, pp. 245-250, Aug. 2000.

(56) **References Cited**

OTHER PUBLICATIONS

U.S. Appl. No. 60/605,066 as provided to WIPO in PCT/US2005/030422, corresponding to U.S. Appl. No. 11/574,290, U.S.publication 2008/0184518, filed Aug. 27, 2004.

U.S. Appl. No. 60/605,181 as provided to WIPO in PCT/US2005/030422, corresponding to U.S. Appl. No. 11/574,290, U.S.publication 2008/0184518, filing date Aug. 27, 2004.

Chae et al., "StarLITE: A new artificial landmark for the navigation of mobile robots," http://www.irc.atr.jp/jk-nrs2005/pdf/Starlite.pdf, 4 pages, 2005.

Chamberlin et al., "Team 1: Robot Locator Beacon System," NASA Goddard SFC, Design Proposal, 15 pages, Feb. 2006.

Champy, "Physical management of IT assets in Data Centers using RFID technologies," RFID 2005 University, Oct. 12-14, 2005, 19 pages.

Chiri, "Joystick Control for Tiny OS Robot," http://www.eecs.berkeley.edu/Programs/ugrad/superb/papers2002/chiri.pdf. 12 pages, Aug. 2002.

Christensen et al. "Theoretical Methods for Planning and Control in Mobile Robotics," 1997 First International Conference on Knowledge-Based Intelligent Electronic Systems, Adelaide, Australia, pp. 81-86, May 1997.

CleanMate 365, Intelligent Automatic Vacuum Cleaner, Model No. QQ-1, User Manual www.metapo.com/support/user_manual.pdf, Dec. 2005, 11 pages.

Clerentin et al., "A localization method based on two omnidirectional perception systems cooperation," *Proc of IEEE International Conference on Robotics & Automation*, San Francisco, CA vol. 2, pp. 1219-1224, Apr. 2000.

Corke, "High Performance Visual serving for robots end-point control," SPIE vol. 2056, Intelligent Robots and Computer Vision, 1993, 10 pages.

Cozman et al., "Robot Localization using a Computer Vision Sextant," IEEE International Midwest Conference on Robotics and Automation, pp. 106-111, 1995.

D'Orazio et al., "Model based Vision System for mobile robot position estimation", *SPIE*, vol. 2058 Mobile Robots VIII, pp. 38-49, 1992.

De Bakker et al., "Smart PSD-array for sheet of light range imaging", Proc. of *SPIE*, vol. 3965, pp. 1-12, May 2000.

Denning Roboscrub image (1989), 1 page.

Desaulniers et al., "An Efficient Algorithm to find a shortest path for a car-like Robot," *IEEE Transactions on robotics and Automation* , 11(6):819-828, Dec. 1995.

Dorfmüller-Ulhaas, "Optical Tracking From User Motion to 3D Interaction," http://www.cg.tuwien.ac.at/research/publications/2002/Dorfmueller-Ulhaas-thesis, 182 pages, 2002.

Dorsch et al., "Laser Triangulation: Fundamental uncertainty in distance measurement," *Applied Optics*, 33(7):1306-1314, Mar. 1994.

Doty et al., "Sweep Strategies for a Sensory-Driven, Behavior-Based Vacuum Cleaning Agent," AAAI 1993 Fall Symposium Series, Instantiating Real-World Agents, pp. 1-6, Oct. 22-24, 1993.

Dudek et al., "Localizing a Robot with Minimum Travel" *Proceedings of the sixth annual ACM-SIAM symposium on Discrete Algorithms*, 27(2):583-604, Apr. 1998.

Dulimarta et al., "Mobile Robot Localization in Indoor Environment", *Pattern Recognition*, 30(1):99-111, 1997.

Dyson's Robot Vacuum Cleaner—the DC06, May 2004, Retrieved from the Internet: URL<http://www.gizmag.com/go/1282/>. Accessed Nov. 2011, 3 pages.

EBay, "Roomba Timer -> Timed Cleaning—Floorvac Robotic Vacuum," Retrieved from the Internet: URL Cgi.ebay.com/ws/eBayISAPI.dll?viewitem&category=43526&item=4375198387 &rd=1, 5 pages, Apr. 2005.

Electrolux Trilobite, Jan. 12, 2001, http://www.electroluxui.com:8080/2002%5C822%5C833102EN.pdf, accessed Jul. 2, 2012, 10 pages.

Eren et al., "Accuracy in position estimation of mobile robots based on coded infrared signal transmission," Proceedings: Integrating Intelligent Instrumentation and Control, Instrumentation and Measurement Technology Conference, 1995, IMTC/95. pp. 548-551, 1995.

Eren et al., "Operation of Mobile Robots in a Structured Infrared Environment," Proceedings 'Sensing, Processing, Networking', IEEE Instrumentation and Measurement Technology Conference, 1997 (IMTC/97), Ottawa, Canada vol. 1, pp. 20-25, May 1997.

Euroflex Intelligente Monstre, 2006, 15 pages (English excerpt only).

Euroflex, Jan. 2006, Retrieved from the Internet: URL<http://www.euroflex.tv/novita_dett.php?id=15, accessed Nov. 2011, 1 page.

eVac Robotic Vacuum S1727 Instruction Manual, Sharper Image Corp, Copyright 2004, 16 pages.

Everyday Robots, "Everyday Robots: Reviews, Discussion and News for Consumers," Aug. 2004, Retrieved from the Internet: URL<www.everydayrobots.com/index.php?option=content &task=view&id=9> (Sep. 2012), 4 pages.

Evolution Robotics, "NorthStar—Low-cost Indoor Localiztion—How it Works," E Evolution Robotics , 2 pages, 2005.

Facchinetti Claudio et al., "Self-Positioning Robot Navigation Using Ceiling Images Sequences," ACCV '95, 5 pages, Dec. 1995.

Facchinetti Claudio et al., "Using and Learning Vision-Based Self-Positioning for Autonomous Robot Navigation," ICARCV '94, vol. 3, pp. 1694-1698, 1994.

Fairfield et al., "Mobile Robot Localization with Sparse Landmarks," SPIE vol. 4573, pp. 148-155, 2002.

Favre-Bulle, "Efficient tracking of 3D—Robot Position by Dynamic Triangulation," IEEE Instrumentation and Measurement Technology Conference IMTC 98 Session on Instrumentation and Measurement in Robotics, vol. 1, pp. 446-449, May 1998.

Fayman, "Exploiting Process Integration and Composition in the context of Active Vision," IEEE Transactions on Systems, Man, and Cybernetics—Part C: Application and reviews, vol. 29, No. 1, pp. 73-86, Feb. 1999.

Floorbot GE Plastics—IMAGE, available at http://www.fuseid.com/, 1989-1990, Accessed Sep. 2012, 1 page.

Floorbotics, VR8 Floor Cleaning Robot, Product Description for Manufacturing, URL: <http://www.consensus.sem.au/SoftwareAwards/CSAarchive/CSA2004/CSAart04/FloorBot/F>. Mar. 2004, 11 pages.

Franz et al., "Biomimetric robot navigation", Robotics and Autonomous Systems, vol. 30 pp. 133-153, 2000.

Fuentes et al., "Mobile Robotics 1994," University of Rochester. Computer Science Department, TR 588, 44 pages, Dec. 1994.

Fukuda et al., "Navigation System based on Ceiling Landmark Recognition for Autonomous mobile robot," 1995 IEEE/RSJ International Conference on Intelligent Robots and Systems 95. 'Human Robot Interaction and Cooperative Robots', Pittsburgh, PA, pp. 1466/1471, Aug. 1995.

Gat, "Robust Low-Computation Sensor-driven Control for Task-Directed Navigation," Proc of IEEE International Conference on Robotics and Automation , Sacramento, CA pp. 2484-2489, Apr. 1991.

Gionis, "A hand-held optical surface scanner for environmental Modeling and Virtual Reality," Virtual Reality World, 16 pages, 1996.

Goel et al., "Systematic Floor Coverage of Unknown Environments Using Rectangular Regions and Localization Certainty," IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS), *IEEE*, Nov. 3-7, 2013, Tokyo, Japan, pp. 1-8.

Goncalves et al., "A Visual Front-End for Simultaneous Localization and Mapping", Proceedings of the 2005 IEEE International Conference on Robotics and Automation, Barcelona, Spain, pp. 44-49, Apr. 2005.

Gregg et al., "Autonomous Lawn Care Applications," 2006 Florida Conference on Recent Advances in Robotics, Miami, Florida, May 25-26, 2006, Florida International University, 5 pages.

Grumet, "Robots Clean House," Popular Mechanics, Nov. 2003, 3 pages.

Gutmann et al., "A Constant-Time Algorithm for Vector Field SLAM Using Exactly Sparse Extended Information Filter," in *Proc. Robotics: Science and Systems*, 2010, 8 pages.

Gutmann et al., "Challenges of Designing a Low-Cost Indoor Localization System Using Active Beacons," IEEE International Confer-

(56) **References Cited**

OTHER PUBLICATIONS

ence on Technologies for Practical Robot Applications (TePRA), *IEEE*, Apr. 22-23, 2013, Woburn, MA, pp. 1-6.

Gutmann et al., "Localization in a Vector Field Map," IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS), *IEEE*, 2012, pp. 3144-3151.

Gutmann et al., "The Social Impact of a Systematic Floor Cleaner," IEEE Workshop on Advanced Robotics and its Social Impacts (ARSO), *IEEE*, May 21-213, 2012, Munich, Germany, pp. 50-53.

Gutmann et al., "Vector Field SLAM," IEEE International Conference on Robotics and Automation (ICRA), *IEEE*, 2010, pp. 236-242.

Hamamatsu "SI PIN Diode S5980, S5981 S5870—Multi-element photodiodes for surface mounting," Hamatsu Photonics, 2 pages, Apr. 2004.

Haralick et al. "Pose Estimation from Corresponding Point Data", *IEEE Transactions on Systems, Man, and Cybernetics*, 19(6):1426-1446, Nov. 1989.

Hausler, "About the Scaling Behaviour of Optical Range Sensors," Fringe '97, Proceedings of the 3rd International Workshop on Automatic Processing of Fringe Patterns, Bremen, Germany, pp. 147-155, Sep. 1997.

Hitachi, accessed at http://www.hitachi.co.jp/New/cnews/hi_030529_hi_030529.pdf , May 29, 2003, 15 pages (with English translation).

Hoag et al., "Navigation and Guidance in interstellar space," ACTA Astronautica, vol. 2, pp. 513-533 , Feb. 1975.

Home Robot—UBOT; Microbotusa.com, retrieved from the WWW at www.microrobotusa.com, accessed Dec. 2, 2008, 2 pages.

Huntsberger et al., "CAMPOUT: A Control Architecture for Tightly Coupled Coordination of Multirobot Systems for Planetary Surface Exploration," *IEEE Transactions on Systems, Man, and Cybernetics—Part A: Systems and Humans*, 33(5):550-559, Sep. 2003.

"It's eye," Retrieved from the Internet: URL< www.hitachi.co.jp/rd/pdf/topics/hitac2003_10.pdf>. 2003, 11 pages (with English translation).

Jarosiewicz et al., "Final Report—Lucid," University of Florida, Departmetn of Electrical and Computer Engineering, EEL 5666—Intelligent Machine Design Laboratory, 50 pages, Aug. 1999.

Jensfelt et al., "Active Global Localization for a mobile robot using multiple hypothesis tracking," *IEEE Transactions on Robots and Automation*, 17(5): 748-760, Oct. 2001.

Jeong et al., "An intelligent map-building system for indoor mobile robot using low cost photo sensors," *SPIE*, vol. 6042, 6 pages, 2005.

Karcher RC 3000 Cleaning Robot—user manual Manufacturer: Alfred-Karcher GmbH & Co, Cleaning Systems, Alfred Karcher—Str 28-40, PO Box 160, D-71349 Winnenden, Germany, Dec. 2002, 8 pages.

Karlsson et al, "Core Technologies for service Robotics," IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS 2004), vol. 3, pp. 2979-2984, Sep. 2004.

Karlsson et al., The vSLAM Algorithm for Robust Localization and Mapping, Proceedings of the 2005 IEEE International Conference on Robotics and Automation, Barcelona, Spain, pp. 24-29, Apr. 2005.

King and Weiman, "HelpmateTM Autonomous Mobile Robots Navigation Systems," SPIE vol. 1388 Mobile Robots, pp. 190-198, 1990.

Kleinberg, The Localization Problem for Mobile Robots, Laboratory for Computer Science, Massachusetts Institute of Technology, 1994 IEEE, pp. 521-531, 1994.

Knights, et al., "Localization and Identification of Visual Landmarks," *Journal of Computing Sciences in Colleges*, 16(4):312-313, May 2001.

Kolodko et al., "Experimental System for Real-Time Motion Estimation," Proceedings of the 2003 IEEE/ASME International Conference on Advanced Intelligent Mechatronics (AIM 2003), pp. 981-986, 2003.

Komoriya et al., "Planning of Landmark Measurement for the Navigation of a Mobile Robot," Proceedings of the 1992 IEEE/RSJ International Cofnerence on Intelligent Robots and Systems, Raleigh, NC pp. 1476-1481, Jul. 1992.

KOOLVAC Robotic Vacuum Cleaner Owner's Manual, Koolatron, 2004, 13 pages.

Krotkov et al., "Digital Sextant," Downloaded from the internet at: http://www.cs.cmu.edu/~epk/ , 1 page, 1995.

Krupa et al., "Autonomous 3-D Positioning of Surgical Instruments in Robotized Laparoscopic Surgery Using Visual Servoin," *IEEE Transactions on Robotics and Automation*, 19(5):842-853, Oct. 2003.

Kuhl et al., "Self Localization in Environments using Visual Angles," VRCAI '04 Proceedings of the 2004 ACM SIGGRAPH international conference on Virtual Reality continuum and its applications in industry, pp. 472-475, 2004.

Kurs et al, Wireless Power transfer via Strongly Coupled Magnetic Resonances, Downloaded from www.sciencemag.org, Aug. 2007, 5 pages.

Kurth, "Range—Only Robot Localization and SLAM with Radio", http://www.ri.cmu.edu/pub_files/pub4/kurth_derek_2004_1/kurth_derek_2004_1.pdf. 60 pages, May 2004, accessed Jul. 27, 2012.

Kwon et al., "Table Recognition through Range-based Candidate Generation and Vision based Candidate Evaluation," ICAR 2007, The 13th International Conference on Advanced Robotics Aug. 21-24, 2007, Jeju, Korea, pp. 918-923, 2007.

Lang et al., "Visual Measurements of Orientation Using Ceiling Features", 1994 IEEE, pp. 552-555, 1994.

Lapin, "Adaptive position estimation for an automated guided vehicle," *SPIE*, vol. 1831 Mobile Robots VII, pp. 82-94, 1992.

LaValle et al., "Robot Motion Planning in a Changing, Partially Predictable Environment," 1994 IEEE International Symposium on Intelligent Control, Columbus, OH, pp. 261-266, Aug. 1994.

Lee et al., "Development of Indoor Navigation system for Humanoid Robot Using Multi-sensors Integration", ION NTM, San Diego, CA pp. 798-805, Jan. 2007.

Lee et al., "Localization Of a Mobile Robot Using the Image of a Moving Object," *IEEE Transaction on Industrial Electronics*, 50(3):612-619, Jun. 2003.

Leonard et al., "Mobile Robot Localization by tracking Geometric Beacons," *IEEE Transaction on Robotics and Automation*, 7(3):376-382, Jun. 1991.

Li et al., "Robust Statistical Methods for Securing Wireless Localization in Sensor Networks," Information Processing in Sensor Networks, 2005, Fourth International Symposium on, pp. 91-98, Apr. 2005.

Li et al., "Making a Local Map of Indoor Environments by Swiveling a Camera and a Sonar," Proceedings of the 1999 IEEE/RSJ International Conference on Intelligent Robots and Systems, pp. 954-959, 1999.

Lin et al., "Mobile Robot Navigation Using Artificial Landmarks," *Journal of robotics System*, 14(2): 93-106, 1997.

Linde, Dissertation—"On Aspects of Indoor Localization," Available at: https://eldorado.tu-dortmund.de/handle/2003/22854, University of Dortmund, 138 pages, Aug. 2006.

Lumelsky et al., "An Algorithm for Maze Searching with Azimuth Input", 1994 IEEE International Conference on Robotics and Automation, San Diego, CA vol. 1, pp. 111-116, 1994.

Luo et al., "Real-time Area-Covering Operations with Obstacle Avoidance for Cleaning Robots," IEEE, pp. 2359-2364, 2002.

Ma, Thesis—"Documentation on Northstar," California Institute of Technology, 14 pages, May 2006.

Madsen et al., "Optimal landmark selection for triangulation of robot position," Journal of Robotics and Autonomous Systems, vol. 13 pp. 277-292, 1998.

Malik et al., "Virtual Prototyping for Conceptual Design of a Tracked Mobile Robot," Electrical and Computer Engineering, Canadian Conference on, IEEE, PI. pp. 2349-2352, May 2006.

Martishevcky, "The Accuracy of point light target coordinate determination by dissectoral tracking system", SPIE vol. 2591, pp. 25-30, Oct. 23, 2005.

Maschinemarkt Würzburg 105, No. 27, pp. 3, 30, Jul. 5, 1999 (with English translation).

Matsutek Enterprises Co. Ltd, "Automatic Rechargeable Vacuum Cleaner," http://matsutek.manufacturer.globalsources.com/si/6008801427181/pdt1/Home-vacuum/10 . . . , Apr. 2007, 3 pages.

(56) **References Cited**

OTHER PUBLICATIONS

McGillem et al., "Infra-red Lacation System for Navigation and Autonomous Vehicles," 1988 IEEE International Conference on Robotics and Automation, vol. 2, pp. 1236-1238, Apr. 1988.

McGillem,et al. "A Beacon Navigation Method for Autonomous Vehicles," *IEEE Transactions on Vehicular Technology*, 38(3):132-139, Aug. 1989.

McLurkin "Stupid Robot Tricks: A Behavior-based Distributed Algorithm Library for Programming Swarms of Robots," Paper submitted for requirements of BSEE at MIT, May 2004, 127 pages.

McLurkin, "The Ants: A community of Microrobots," Paper submitted for requirements of BSEE at MIT, May 1995, 60 pages.

Michelson, "Autonomous navigation," McGraw-Hill—Access Science, Encyclopedia of Science and Technology Online, 2007, 4 pages.

Miro et al., "Towards Vision Based Navigation in Large Indoor Environments," Proceedings of the IEEE/RSJ International Conference on Intelligent Robots and Systems, Beijing, China, pp. 2096-2102, Oct. 2006.

Monteiro et al., "Visual Servoing for Fast Mobile Robot: Adaptive Estimation of Kinematic Parameters," Proceedings of the IECON '93., International Conference on Industrial Electronics, Maui, HI, pp. 1588-1593, Nov. 1993.

Moore et al., "A simple Map-bases Localization strategy using range measurements," *SPIE*, vol. 5804 pp. 612-620, 2005.

Munich et al., "ERSP: A Software Platform and Architecture for the Service Robotics Industry," Intelligent Robots and Systems, 2005. (IROS 2005), pp. 460-467, Aug. 2005.

Munich et al., "SIFT-ing Through Features with ViPR", IEEE Robotics & Automation Magazine, pp. 72-77, Sep. 2006.

Nam et al., "Real-Time Dynamic Visual Tracking Using PSD Sensors and extended Trapezoidal Motion Planning", Applied Intelligence 10, pp. 53-70, 1999.

Nitu et al., "Optomechatronic System for Position Detection of a Mobile Mini-Robot," *IEEE Ttransactions on Industrial Electronics*, 52(4):969-973, Aug. 2005.

"NorthStar, Low-Cost, Indoor Localization," Evolution Robotics—Powering Intelligent Products, 2005, 2 pages.

Pages et al., "A camera-projector system for robot positioning by visual serving," Proceedings of the 2006 Conference on Computer Vision and Pattern Recognition Workshop (CVPRW06), 8 pages, Jun. 2006.

Pages et al., "Optimizing Plane-to-Plane Positioning Tasks by Image-Based Visual Servoing and Structured Light," *IEEE Transactions on Robotics*, 22(5):1000-1010, Oct. 2006.

Pages et al., "Robust decoupled visual servoing based on structured light," 2005 IEEE/RSJ, Int. Conf. on Intelligent Robots and Systems, pp. 2676-2681, 2005.

Park et al., "A Neural Network Based Real-Time Robot Tracking Controller Using Position Sensitive Detectors," IEEE World Congress on Computational Intelligence., 1994 IEEE International Conference on Neutral Networks, Orlando, Florida pp. 2754-2758, Jun./Jul. 1994.

Park et al., "Dynamic Visual Servo Control of Robot Manipulators using Neutral Networks," *The Korean Institute Telematics and Electronics*, 29-B(10):771-779, Oct. 1992.

Paromtchik "Toward Optical Guidance of Mobile Robots," Proceedings of the Fourth World Multiconference on Systemics, Cybermetics and Informatics, Orlando, FL, USA, Jul. 23, 2000, vol. IX, pp. 44-49, available at http://emotion.inrialpes.fr/~paromt/infos/papers/paromtchik:asama:sci:2000.ps.gz, accessed Jul. 3, 2012, 6 pages.

Paromtchik et al., "Optical Guidance System for Multiple mobile Robots," Proceedings 2001 ICRA. IEEE International Conference on Robotics and Automation, vol. 3, pp. 2935-2940, May 2001.

Penna et al., "Models for Map Building and Navigation", IEEE Transactions on Systems. Man. and Cybernetics., 23(5):1276-1301, Sep./Oct. 1993.

Pirjanian et al. "Representation and Execution of Plan Sequences for Multi-Agent Systems," Proceedings of the 2001 IEEE/RSJ International Conference on Intelligent Robots and Systems, Maui, Hawaii, pp. 2117-2123, Oct. 2001.

Pirjanian et al., "A decision-theoretic approach to fuzzy behavior coordination", 1999 IEEE International Symposium on Computational Intelligence in Robotics and Automation, 1999. CIRA '99., Monterey, CA, pp. 101-106, Nov. 1999.

Pirjanian et al., "Distributed Control for a Modular, Reconfigurable Cliff Robot," Proceedings of the 2002 IEEE International Conference on Robotics & Automation, Washington, D.C. pp. 4083-4088, May 2002.

Pirjanian et al., "Improving Task Reliability by Fusion of Redundant Homogeneous Modules Using Voting Schemes," Proceedings of the 1997 IEEE International Conference on Robotics and Automation, Albuquerque, NM, pp. 425-430, Apr. 1997.

Pirjanian et al., "Multi-Robot Target Acquisition using Multiple Objective Behavior Coordination," Proceedings of the 2000 IEEE International Conference on Robotics & Automation, San Francisco, CA, pp. 2696-2702, Apr. 2000.

Pirjanian, "Challenges for Standards for consumer Robotics," IEEE Workshop on Advanced Robotics and its Social impacts, pp. 260-264, Jun. 2005.

Pirjanian, "Reliable Reaction," Proceedings of the 1996 IEEE/SICE/RSJ International Conference on Multisensor Fusion and Integration for Intelligent Systems, pp. 158-165, 1996.

Prassler et al., "A Short History of Cleaning Robots," Autonomous Robots 9, 211-226, 2000, 16 pages.

Remazeilles et al., "Image based robot navigation in 3D environments," Proc. of *SPIE*, vol. 6052, pp. 1-14, Dec. 2005.

Rives et al., "Visual servoing based on ellipse features," *SPIE*, vol. 2056 Intelligent Robots and Computer Vision pp. 356-367, 1993.

Roboking—not just a vacuum cleaner, a robot!, Jan. 21, 2004, infocom.uz/2004/01/21/robokingne-prosto-pyilesos-a-robot/, accessed Oct. 10, 2011, 5 pages.

Robotics World, "A Clean Sweep," 5 pages, Jan. 2001.

Roth-Tabak et al., "Environment Model for mobile Robots Indoor Navigation," *SPIE*, vol. 1388 Mobile Robots, pp. 453-463, 1990.

Sahin et al., "Development of a Visual Object Localization Module for Mobile Robots," 1999 Third European Workshop on Advanced Mobile Robots, (Eurobot '99), pp. 65-72, 1999.

Salomon et al., "Low-Cost Optical Indoor Localization system for Mobile Objects without Image Processing," IEEE Conference on Emerging Technologies and Factory Automation, 2006. (ETFA '06), pp. 629-632, Sep. 2006.

Sato, "Range Imaging Based on Moving Pattern Light and Spatio-Temporal Matched Filter," Proceedings International Conference on Image Processing, vol. 1., Lausanne, Switzerland, pp. 33-36, Sep. 1996.

Schenker et al., "Lightweight rovers for Mars science exploration and sample return," Intelligent Robots and Computer Vision XVI, *SPIE* Proc. 3208, pp. 24-36, 1997.

Schofield, "Neither Master Nor slave—A Practical Study in the Development and Employment of Cleaning Robots, Emerging Technologies and Factory Automation," 1999 Proceedings ETFA '99 1999 7th IEEE International Conference on Barcelona, Spain, pp. 1427-1434, Oct. 1999.

Shimoga et al., "Touch and Force Reflection for Telepresence Surgery," Engineering in Medicine and Biology Society, 1994. Engineering Advances: New Opportunities for Biomedical Engineers. Proceedings of the 16th Annual International Conference of the IEEE, Baltimore, MD, pp. 1049-1050, 1994.

Sim et al, "Learning Visual Landmarks for Pose Estimation," IEEE International Conference on Robotics and Automation, vol. 3, Detroit, MI, pp. 1972-1978, May 1999.

Sobh et al., "Case Studies in Web-Controlled Devices and Remote Manipulation," Automation Congress, 2002 Proceedings of the 5th Biannual World, pp. 435-440, Dec. 2002.

Stella et al., "Self-Location for Indoor Navigation of Autonomous Vehicles," Part of the SPIE conference on Enhanced and Synthetic Vision SPIE vol. 3364, pp. 298-302, 1998.

Summet, "Tracking Locations of Moving Hand-held Displays Using Projected Light," Pervasive 2005, LNCS 3468, pp. 37-46, 2005.

(56) **References Cited**

OTHER PUBLICATIONS

Svedman et al., "Structure from Stereo Vision using Unsynchronized Cameras for Simultaneous Localization and Mapping," 2005 IEEE/RSJ International Conference on Intelligent Robots and Systems, pp. 2993-2998, 2005.

SVET Computers—New Technologies—Robot Vacuum Cleaner, Oct. 1999, available at http://www.sk.rs/1999/10/sknt01.html, 1 page, accessed Nov. 1, 2011.

Takio et al., "Real-Time Position and Pose Tracking Method of Moving Object Using Visual Servo System," 47th IEEE International Symposium on Circuits and Systems, pp. 167-170, 2004.

Terada et al., "An Acquisition of the Relation between Vision and Action using Self-Organizing Map and Reinforcement Learning," 1998 Second International Conference on Knowledge-Based Intelligent Electronic Systems, Adelaide, Australia, pp. 429-434, Apr. 1998.

TheRobotStore.com, "Friendly Robotics Robotic Vacuum RV400—The Robot Store," www.therobotstore.com/s.nl/sc.9/category.-109/it.A/id.43/.f, 1 page, Apr. 2005.

Thrun, Sebastian, "Learning Occupancy Grid Maps With Forward Sensor Models," Autonomous Robots 15, 28 pages, Sep. 1, 2003.

Trebi-Ollennu et al., "Mars Rover Pair Cooperatively Transporting a Long Payload," Proceedings of the 2002 IEEE International Conference on Robotics & Automation, Washington, D.C. pp. 3136-3141, May 2002.

Tribelhorn et al., "Evaluating the Roomba: A low-cost, ubiquitous platform for robotics research and education," *IEEE*, pp. 1393-1399, 2007.

Tse et al., "Design of a Navigation System for a Household Mobile Robot Using Neural Networks," Department of Manufacturing Engg. & Engg. Management, City University of Hong Kong, pp. 2151-2156, 1998.

UAMA (Asia) Industrial Co., Ltd., "RobotFamily," 2005, 1 page.

Watanabe et al., "Position Estimation of Mobile Robots With Internal and External Sensors Using Uncertainty Evolution Technique," 1990 IEEE International Conference on Robotics and Automation, Cincinnati, OH, pp. 2011-2016, May 1990.

Watts, "Robot, boldly goes where no man can," The Times—pp. 20, Jan. 1985.

Wijk et al., "Triangulation-Based Fusion of Sonar Data with Application in Robot Pose Tracking," *IEEE Transactions on Robotics and Automation*, 16(6):740-752, Dec. 2000.

Wolf et al., "Robust Vision-Based Localization by Combining an Image-Retrieval System with Monte Carol Localization,", *IEEE Transactions on Robotics*, 21(2):208-216, Apr. 2005.

Wolf et al., "Robust Vision-based Localization for Mobile Robots Using an Image Retrieval System Based on Invariant Features," Proceedings of the 2002 IEEE International Conference on Robotics & Automation, Washington, D.C., pp. 359-365, May 2002.

Wong, "EIED Online>> Robot Business", ED Online ID# 13114, 17 pages, Jul. 2006.

Yamamoto et al., "Optical Sensing for Robot Perception and Localization," 2005 IEEE Workshop on Advanced Robotics and its Social Impacts, pp. 14-17, 2005.

Yata et al., "Wall Following Using Angle Information Measured by a Single Ultrasonic Transducer," Proceedings of the 1998 IEEE, International Conference on Robotics & Automation, Leuven, Belgium, pp. 1590-1596, May 1998.

Yun et al., "Image-Based Absolute Positioning System for Mobile Robot Navigation," IAPR International Workshops SSPR, Hong Kong, pp. 261-269, Aug. 2006.

Yun et al., "Robust Positioning a Mobile Robot with Active Beacon Sensors," *Lecture Notes in Computer Science*, 2006, vol. 4251, pp. 890-897, 2006.

Yuta et al., "Implementation of an Active Optical Range sensor Using Laser Slit for In-Door Intelligent Mobile Robot," IEE/RSJ International Workshop on Intelligent Robots and Systems (IROS 91) vol. 1, Osaka, Japan, pp. 415-420, Nov. 3-5, 1991.

Zha et al., "Mobile Robot Localization Using Incomplete Maps for Change Detection in a Dynamic Environment," Advanced Intelligent Mechatronics '97. Final Program and Abstracts., IEEE/ASME International Conference, pp. 110, Jun. 1997.

Zhang et al., "A Novel Mobile Robot Localization Based on Vision," *SPIE* vol. 6279, 6 pages, Jan. 2007.

Electrolux Trilobite, "Time to enjoy life," Retrieved from the Internet: URL<http://www.robocon.co.kr/trilobite/Presentation_Trilobite_Kor_030104.ppt, 10 pages, accessed Dec. 2011 (publication date-Mar. 1, 2004).

Electrolux, "Designed for the well-lived home," Retrieved from the Internet: URL<http://www.electroluxusa.com/node57.as[?currentURL=node142.asp%3F >. Accessed Mar. 18, 2005, 2 pages (publication date-no date found).

Facts on Trilobite, webpage, Retrieved from the Internet: URL<http://trilobiteelectroluxse/presskit_en/model11335asp?print=yes&pressID=>. 2 pages, accessed Dec. 12, 2003 (publication date-no date found).

Friendly Robotics, "Friendly Robotics—Friendly Vac, Robotic Vacuum Cleaner," Retrieved from the Internet: URL<www.friendlyrobotics.com/vac.htm> 4 pages, Apr. 20, 2005 (publication date-no date found).

Friendly Robotics, Retrieved from the Internet: URL<http://www.robotsandrelax.com/PDFs/RV400Manual.pdf>. 18 pages, accessed Dec. 2011 (publication date-2004).

Hitachi: News release: "The home cleaning robot of the autonomous movement type (experimental machine)," Retrieved from the Internet: URL<www.i4u.com./japanreleases/hitachirobot.htm>. 5 pages, Mar. 18, 2005 (publication date-May 29, 2003).

Iirobotics.com, "Samsung Unveils Its Multifunction Robot Vacuum," Retrieved from the Internet: URL<.www.iirobotics.com/webpages/hotstuff.php?ubre=111>. 3 pages, accessed Mar. 18, 2005 (publication date-Aug. 31, 2004).

InMach "Intelligent Machines," Retrieved from the Internet: URL<www.inmach.de/inside.html>. 1 page, Accessed Nov. 19, 2008 (publication date no date found).

Innovation First, "2004 EDU Robot Controller Reference Guide," Retrieved from the Internet: URL<http://www.ifirobotics.com>. 13 pages, Mar. 2004 (publication date-Mar. 1, 2004).

IT media, Retrieved from the Internet: URL<http://www.itmedia.co.jp/news/0111/16/robofesta_m.html>. Accessed Nov. 1, 2011, 8 pages (with English translation), (publication date-Nov. 16, 2001).

Kahney, "Robot Vacs are in the House," Retrieved from the Internet: URL<www.wired.com/news/technology/o,1282,59237,00.html>. Accessed Mar. 18, 2005, 5 pages, (publication date-Jun. 16, 2003).

Karcher "Karcher RoboCleaner RC 3000," Retrieved from the Internet: URL<www.robocleaner.de/english/screen3.html>. 4 pages, accessed Dec. 2003 (publication date-no date found).

Karcher RC3000 RoboCleaner,—IMAGE, Accessed at <http://www.karcher.de/versions/int/assets/video/2_4_robo_en.swf>. Accessed Sep. 2009, 1 page (publication date-no date found).

Karcher USA, RC3000 Robotic Cleaner, website: http://www.karcherusa.com/showproducts.php?op=view prod&param1=143&param2=&param3=, 3 pages, accessed Mar. 2005, (publication date-2005).

Lambrinos et al., "A mobile robot employing insect strategies for navigation," Retrieved from the Internat: URL<http://www8.cs.umu.se/kurser/TDBD17/VT04/dl/Assignment%20Pa pers/lambrinos-RAS-2000.pdf>. 38 pages, (publication date-Feb. 19, 1999).

Matsumura Camera Online Shop: Retrieved from the Internet: URL<http://www.rakuten.co.jp/matsucame/587179/711512/>. Accessed Nov. 2011, 15 pages (with English translation), (publication date-no date found).

MobileMag, "Samsung Unveils High-tech Robot Vacuum Cleaner," Retrieved from the Internet: URL<http://www.mobilemag.com/content/100/102/C2261/>. 4 pages, accessed Mar. 2005 (publication date-Nov. 25, 2003).

Morland,"Autonomous Lawnmower Control", Downloaded from the Internet at: http://cns.bu.edu/~cjmorlan/robotics/lawnmower/report.pdf, 10 pages, Jul. 2002 (publication date-Jul. 24, 2002).

On Robo, "Robot Reviews Samsung Robot Vacuum (VC-RP30W)," Retrieved from the Internet: URL <www.onrobo.com/reviews/AT_Home/vacuum_cleaners/on00vcrb30rosam/index.htm>. 2 pages, accessed Mar. 18, 2005 (publication date-2005).

(56) **References Cited**

OTHER PUBLICATIONS

Put Your Roomba . . . On, Automatic webpages: http://www.acomputeredge.com/roomba, 3 pages, accessed Apr. 20, 2005 (publication date-no date found).

RoboMaid Sweeps Your Floors So You Won't Have To, the Official Site, website: Retrieved from the Internet: URL<http://therobomaid.com/>. 2 pages, accessed Mar. 18, 2005 (publication date-no date found).

Robot Buying Guide, "LG announces the first robotic vacuum cleaner for Korea," Retrieved from the Internet: URL<http://robotbg.com/news/2003/04/22/lg_announces_the_first_robotic_vacu>. 1 page, (publication date-Apr. 22, 2003).

Ronnback, "On Methods for Assistive Mobile Robots," Retrieved from the Internet: URL<http://www.openthesis.org/documents/methods-assistivemobile-robots-595019.html>. 218 pages (publication date-2006).

Schlemmer, "Electrolux Trilobite Robotic Vacuum," Retrieved from the Internet: URL<www.hammacher.com/publish/71579.asp?promo=xsells>. 3 pages, accessed Mar. 18, 2005 (publication date-2004).

Special Reports, "Vacuum Cleaner Robot Operated in Conjunction with 3G Celluar Phone," 59(9): 3 pages, Retrieved from the Internet: URLhttp://www.toshiba.co.jp/tech/review/2004/09/59_0 (publication date-2004).

Taipei Times, "Robotic vacuum by Matsuhita about to undergo testing," Retrieved from the Internet: URL<http://www.taipeitimes.com/News/worldbiz/archives/2002/03/26/0000129338>. Accessed Nov. 1, 2011, 2 pages (publication date-Mar. 26, 2002).

"Tech-on!," Retrieved from the Internet: URL http://techon.nikkeibp.co.jp/members/01db/200203/1006501/, accessed Nov. 1, 2011, 7 pages (with English translation), (publication date-Mar. 25, 2002).

Teller, "Pervasive pose awareness for people, Objects and Robots," http://www.ai.mit.edu/lab/dangerous-ideas/Spring2003/teller-pose.pdf, 22 pages, (publication date-Apr. 30, 2003).

The Sharper Image, eVac Robotic Vacuum—Product Details, www.sharperiamge.com/us/en/templates/products/pipmoreworklprintable.jhtml, 1 page, accessed Mar. 18, 2005, (publication date-no date found).

TotalVac.com, RC3000 RoboCleaner website, Accessed at http://ww.totalvac.com/robot_vacuum.htm, accessed Mar. 18, 2005, 3 pages (publication date-2004).

UBOT, cleaning robot capable of wiping with a wet duster, Retrieved from the Internet: URL<http://us.aving.net/news/view.php?articleId=23031>. 4 pages, accessed Nov. 1, 2011 (publication date-Aug. 25, 2008).

Yujin Robotics,"An intelligent cleaning robot," Retrieved from the Internet: URL<http://us.aving.net/news/view.php?articleId=7257>. 8 pages, accessed Nov. 4, 2011 (publication date-Sep. 2, 2008).

Zoombot Remote Controlled Vaccuum-RV-500 NEW Roomba 2, website: http://cgi.ebay.com/ws/eBayISAPI.dll?ViewItem&category=43526&item=4373497618&rd=1, accessed Apr. 20, 2005, 7 pages (publication date-Apr. 13, 2005).

* cited by examiner

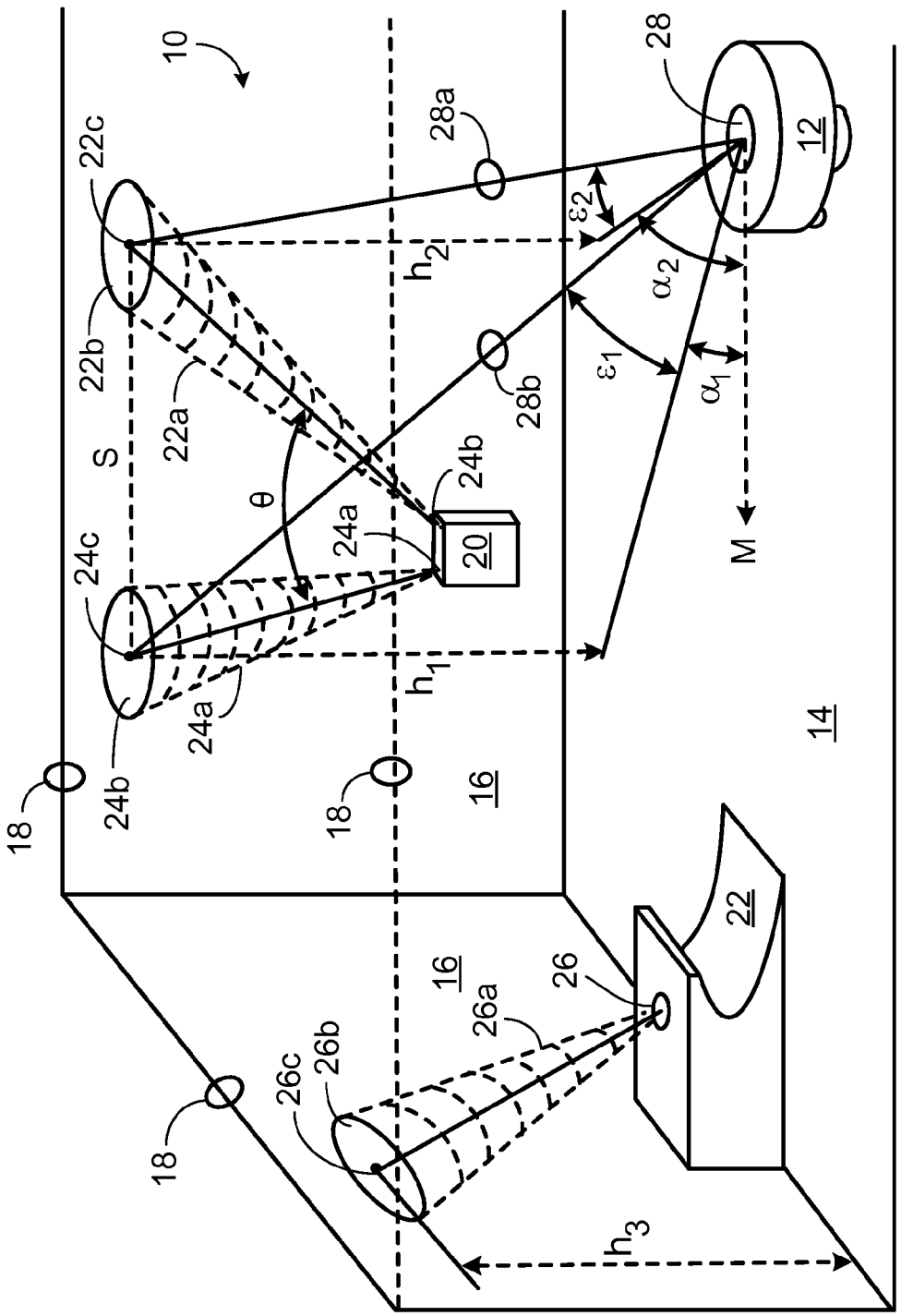

10
28
28a
12
22c
ε_2
h_2
α_2
22b
28b
ε_1
α_1
S
22a
θ
24b
24a
20
M
24c
h_1
24a
24b
14
18
18
16
22
16
26
26a
26c
26b
18
h_3

FIG. 1

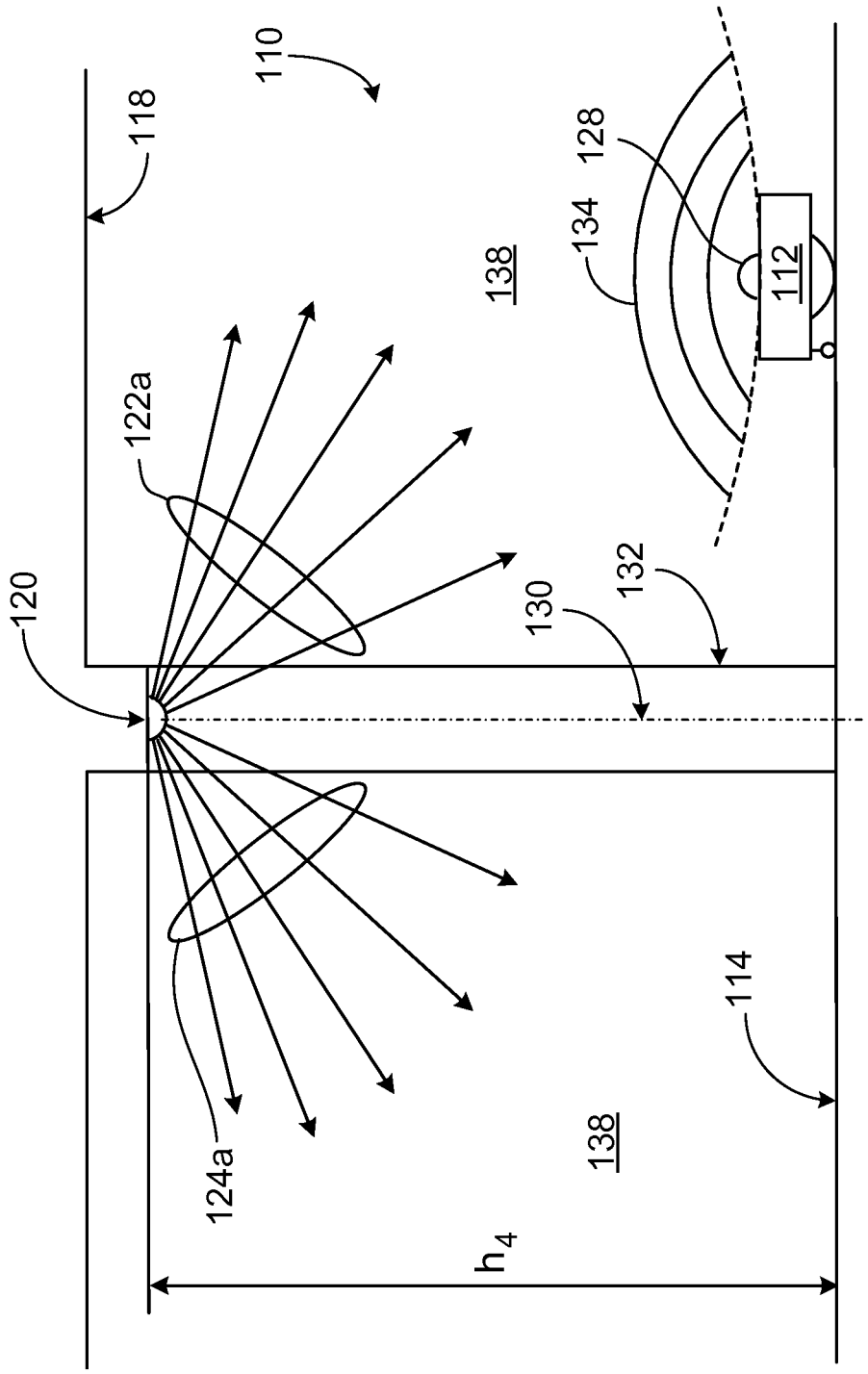


FIG. 2

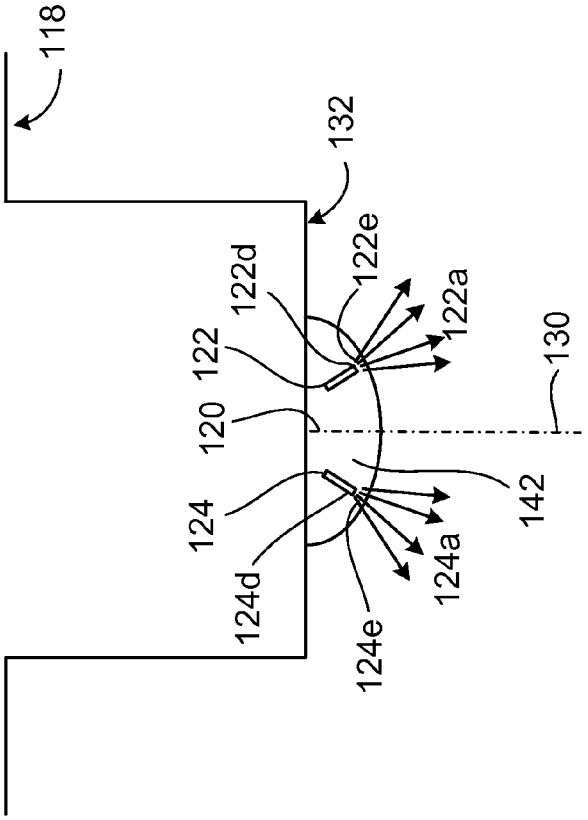

118
132
122e
122d
122a
122
120
130
124
142
124d
124a
124e

FIG. 3B

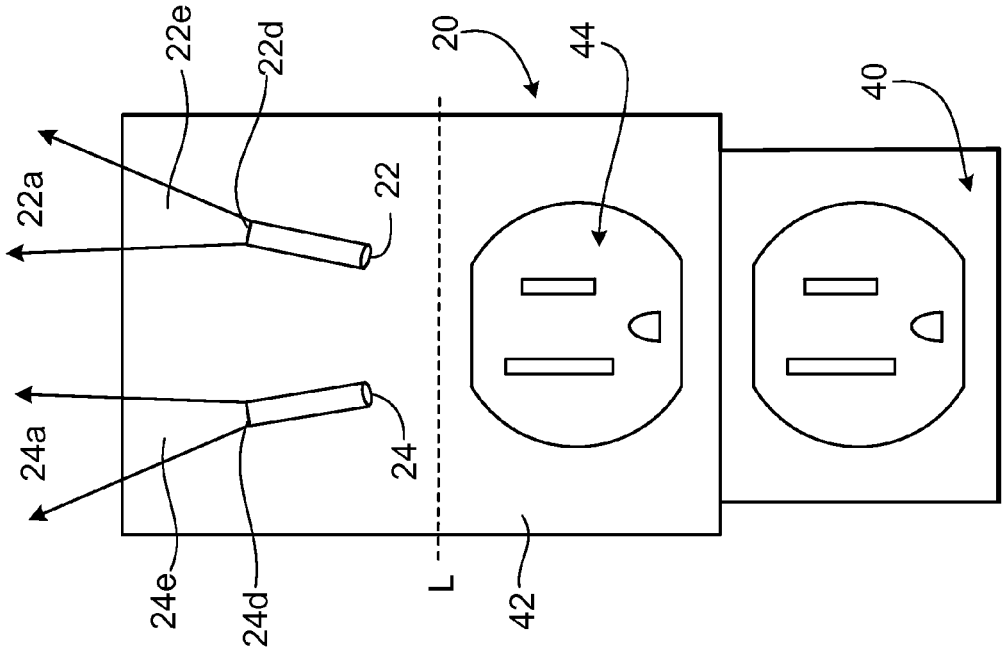

22e
22d
20
44
40
22a
22
24a
24
24e
24d
L
42

FIG. 3A

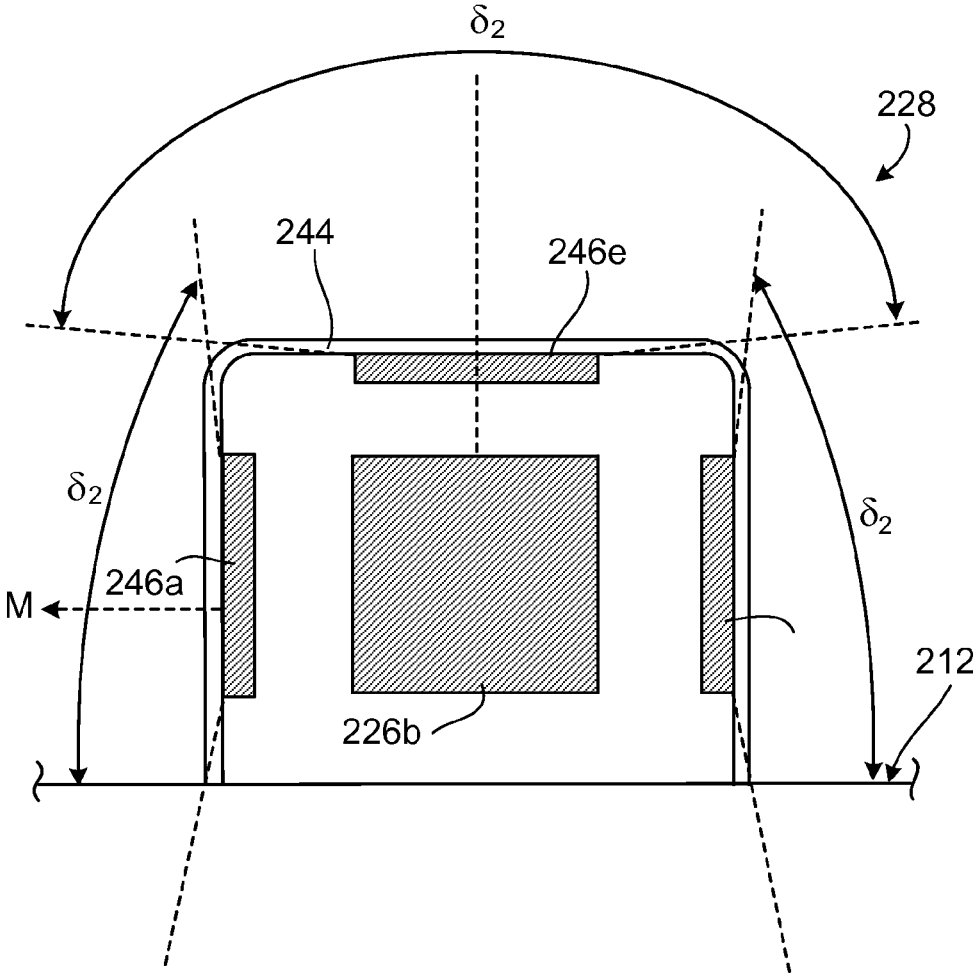


FIG. 4A

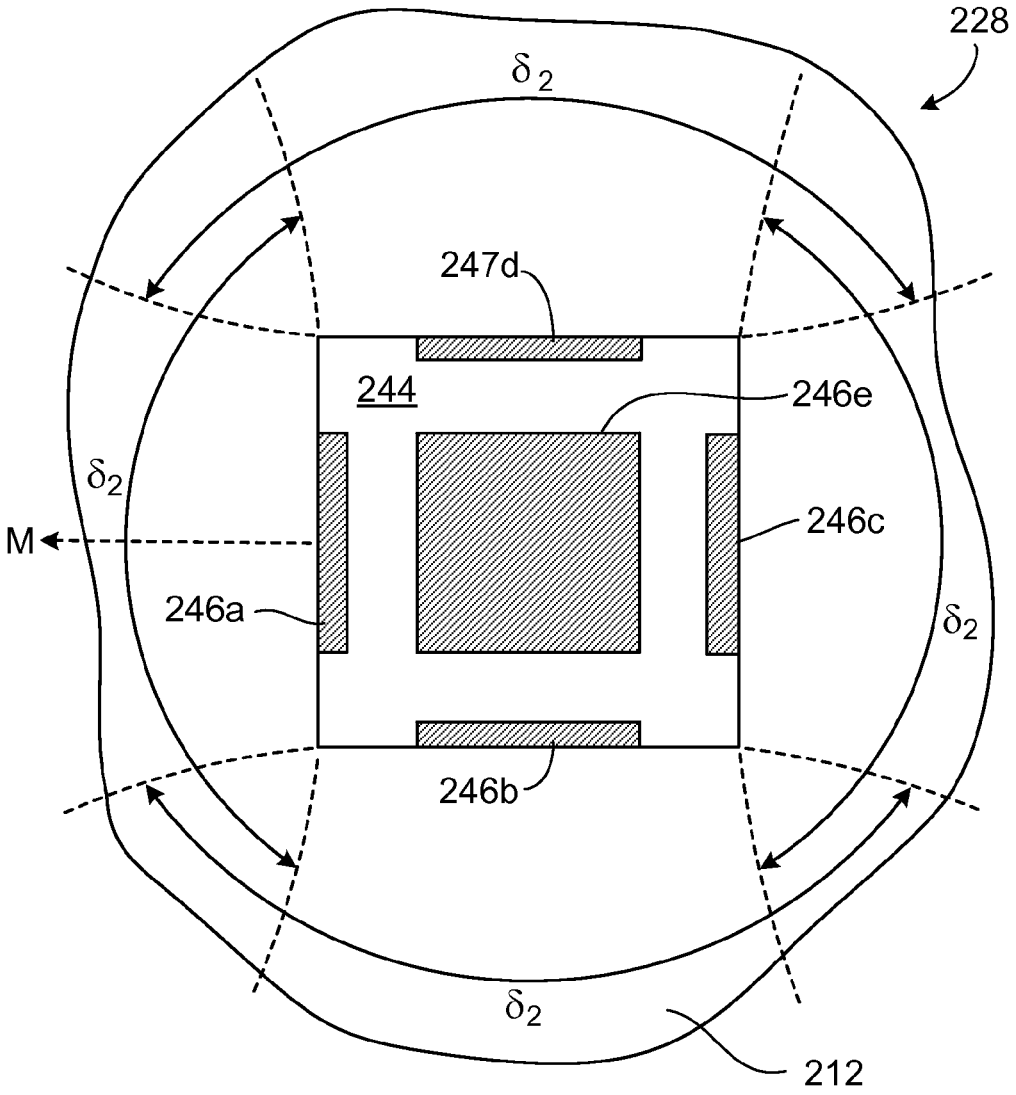

228
δ_2
247d
244
246e
δ_2
M
246c
246a
δ_2
246b
δ_2
212

FIG. 4B

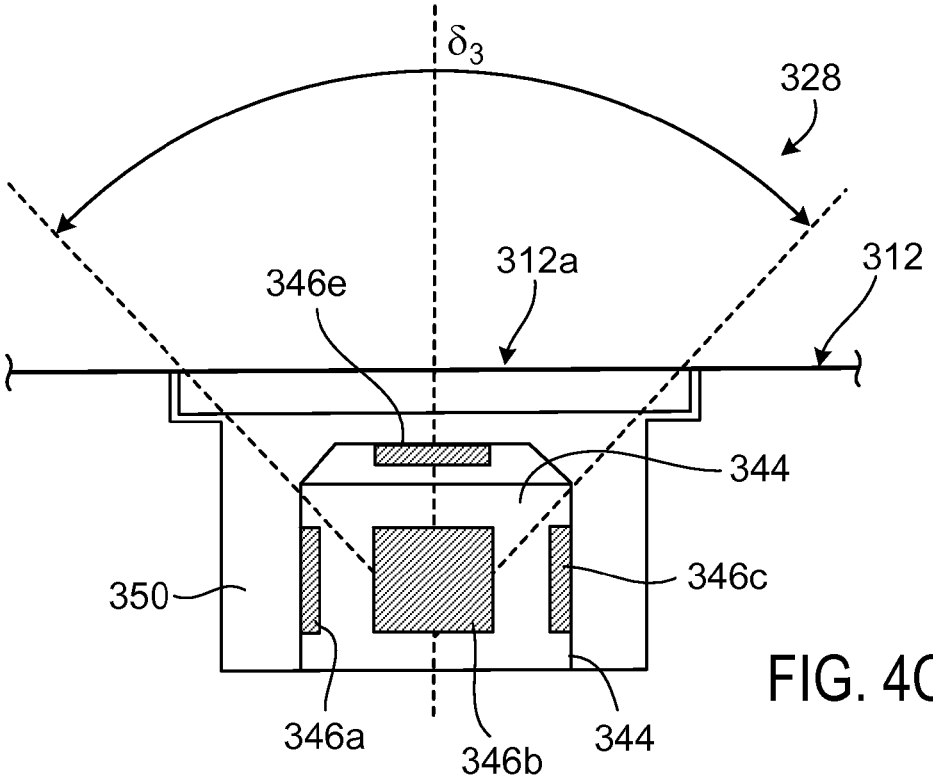

δ_3
328
312a
312
346e
344
350
346c
346a
346b
344

FIG. 4C

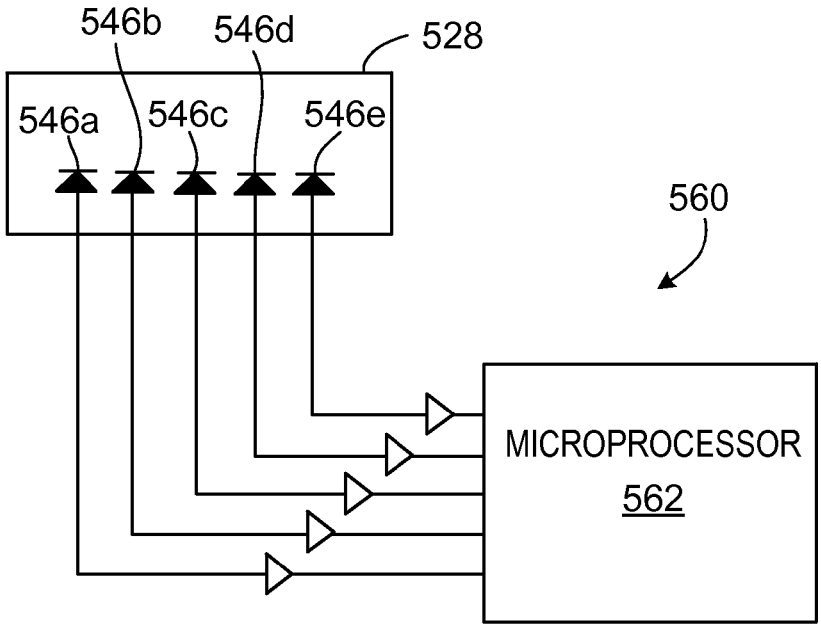

546b
546d
528
546a
546c
546e
560
MICROPROCESSOR
562

FIG. 5A

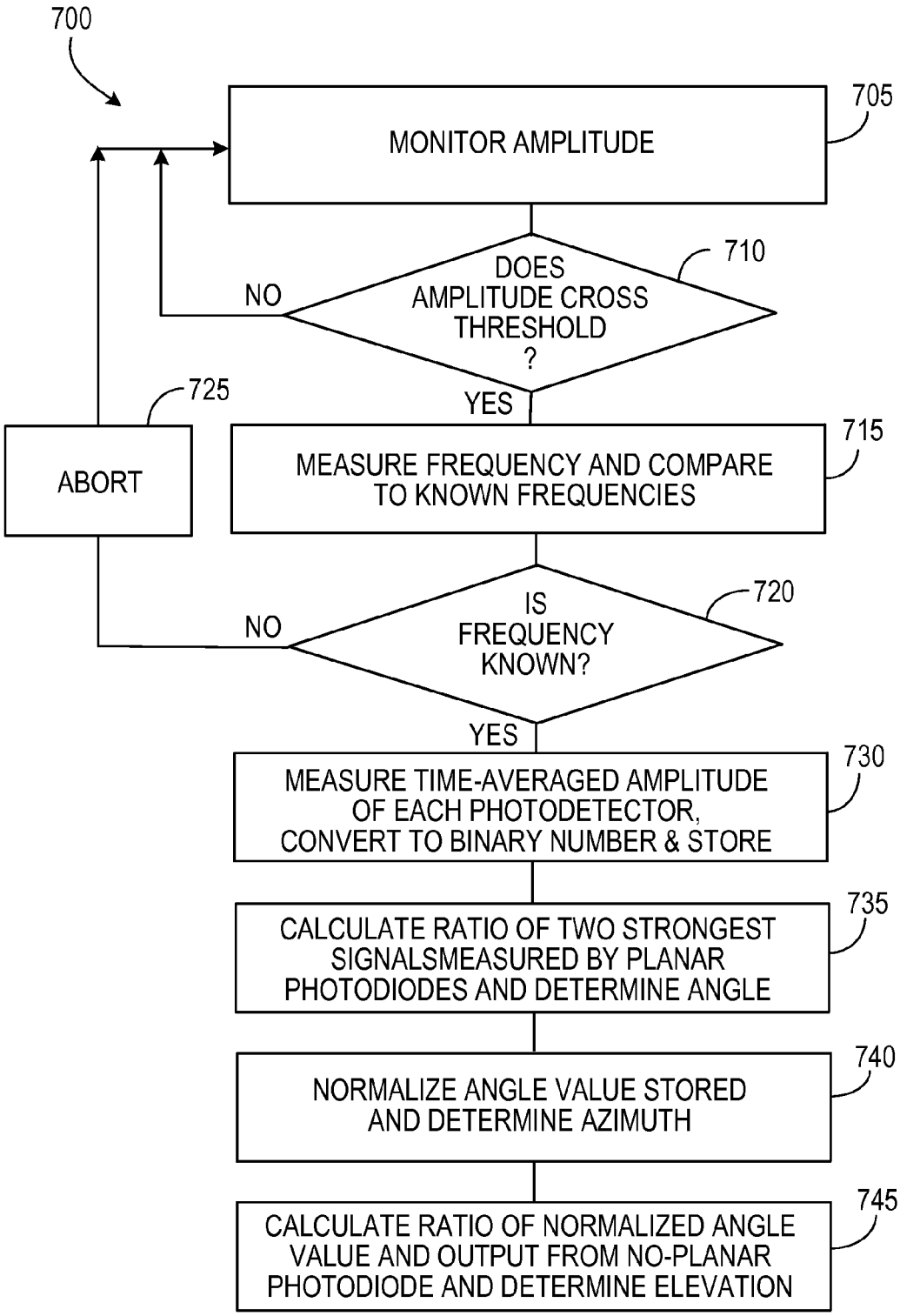

700
MONITOR AMPLITUDE
705
DOES AMPLITUDE CROSS THRESHOLD ?
710
NO
YES
ABORT
725
MEASURE FREQUENCY AND COMPARE TO KNOWN FREQUENCIES
715
IS FREQUENCY KNOWN?
720
NO
YES
MEASURE TIME-AVERAGED AMPLITUDE OF EACH PHOTODETECTOR, CONVERT TO BINARY NUMBER & STORE
730
CALCULATE RATIO OF TWO STRONGEST SIGNALSMEASURED BY PLANAR PHOTODIODES AND DETERMINE ANGLE
735
NORMALIZE ANGLE VALUE STORED AND DETERMINE AZIMUTH
740
CALCULATE RATIO OF NORMALIZED ANGLE VALUE AND OUTPUT FROM NO-PLANAR PHOTODIODE AND DETERMINE ELEVATION
745

FIG. 5B

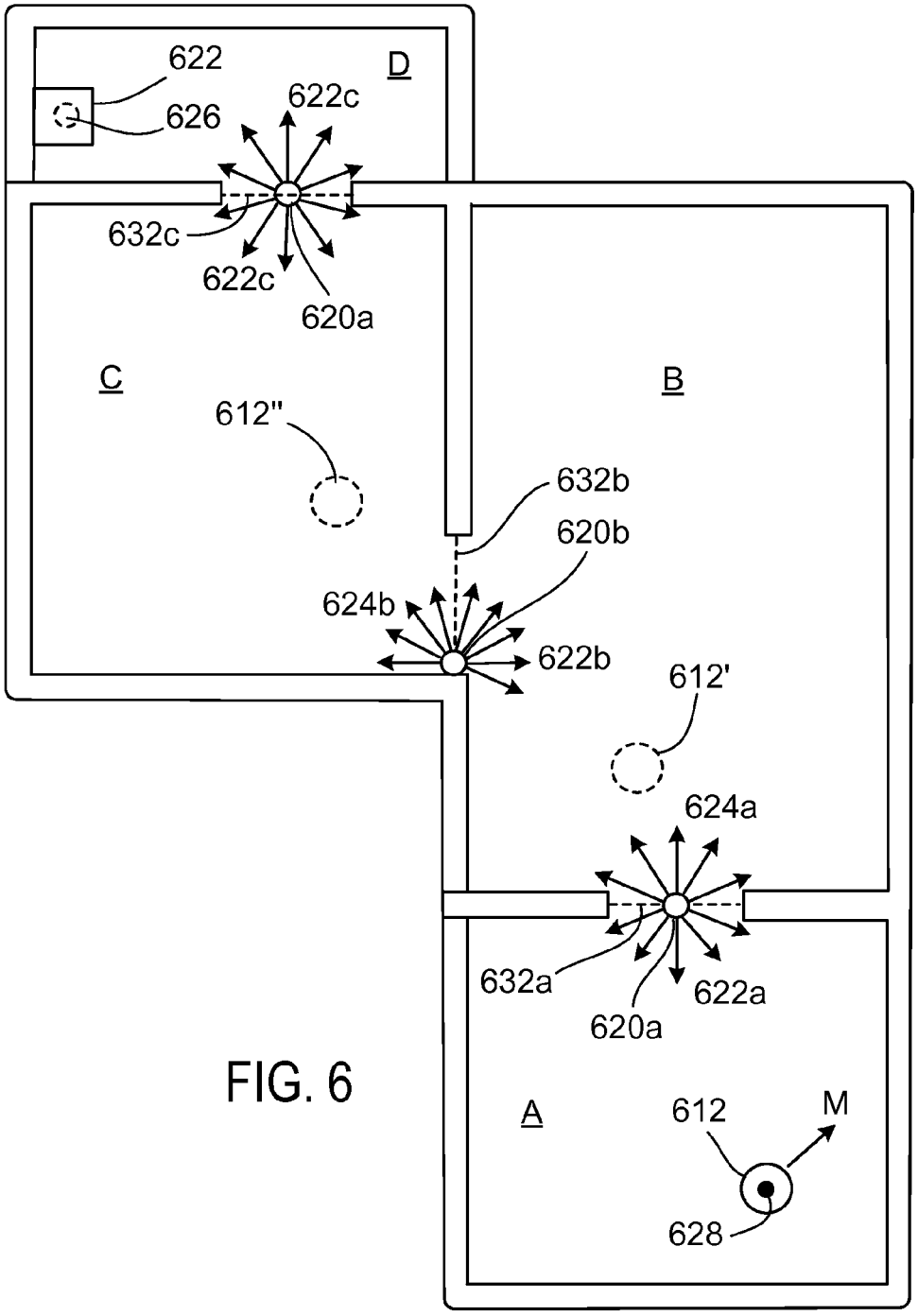

622
626
D
622c
632c
622c
620a
C
B
612"
632b
620b
624b
622b
612'
624a
632a
622a
620a
A
612
M
628

FIG. 6

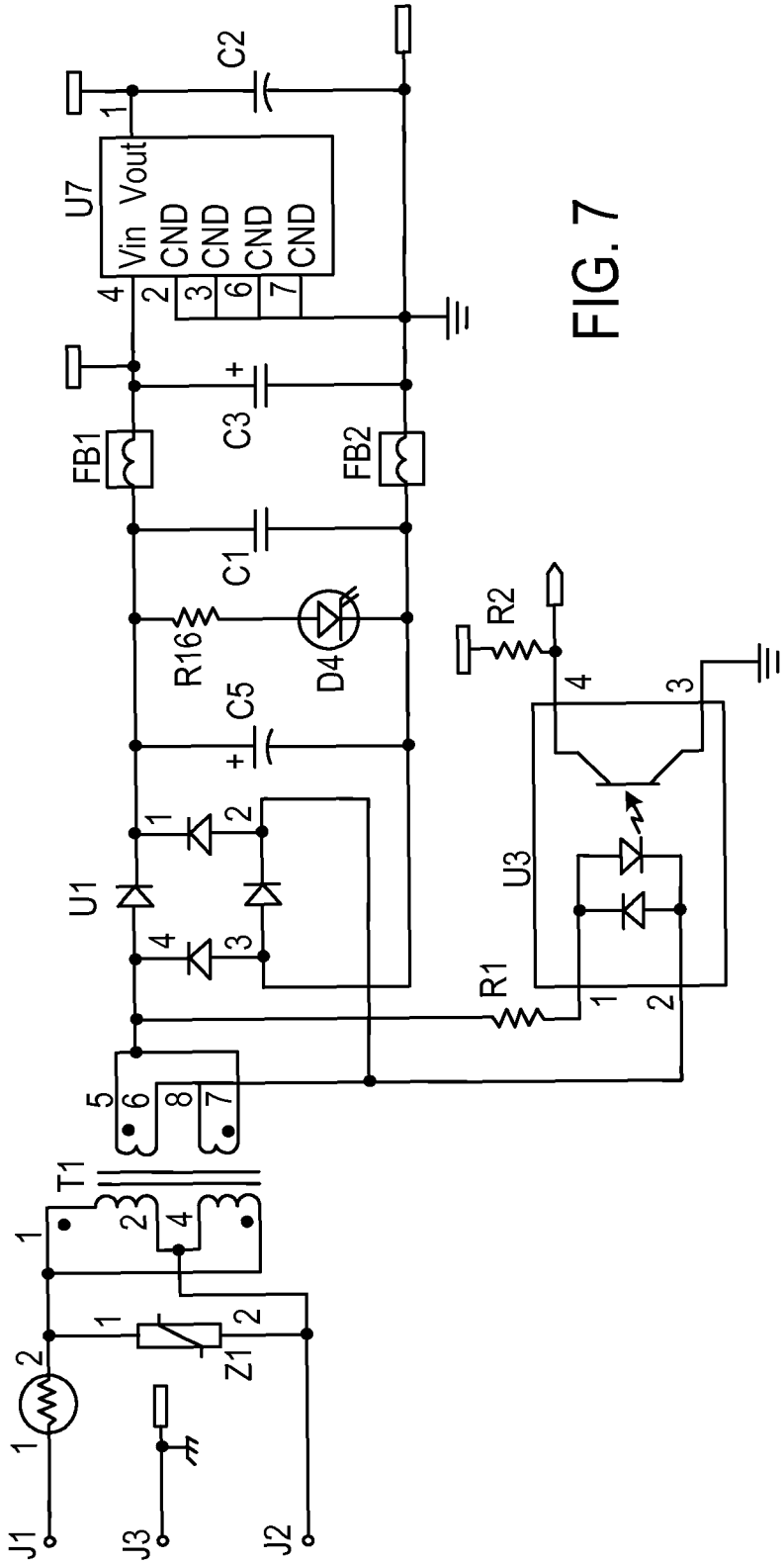

C2
U7
Vin
Vout
CND
CND
CND
CND
C3
FB1
FB2
C1
R16
D4
C5
R2
U3
U1
R1
T1
Z1
J1
J3
J2

FIG. 7

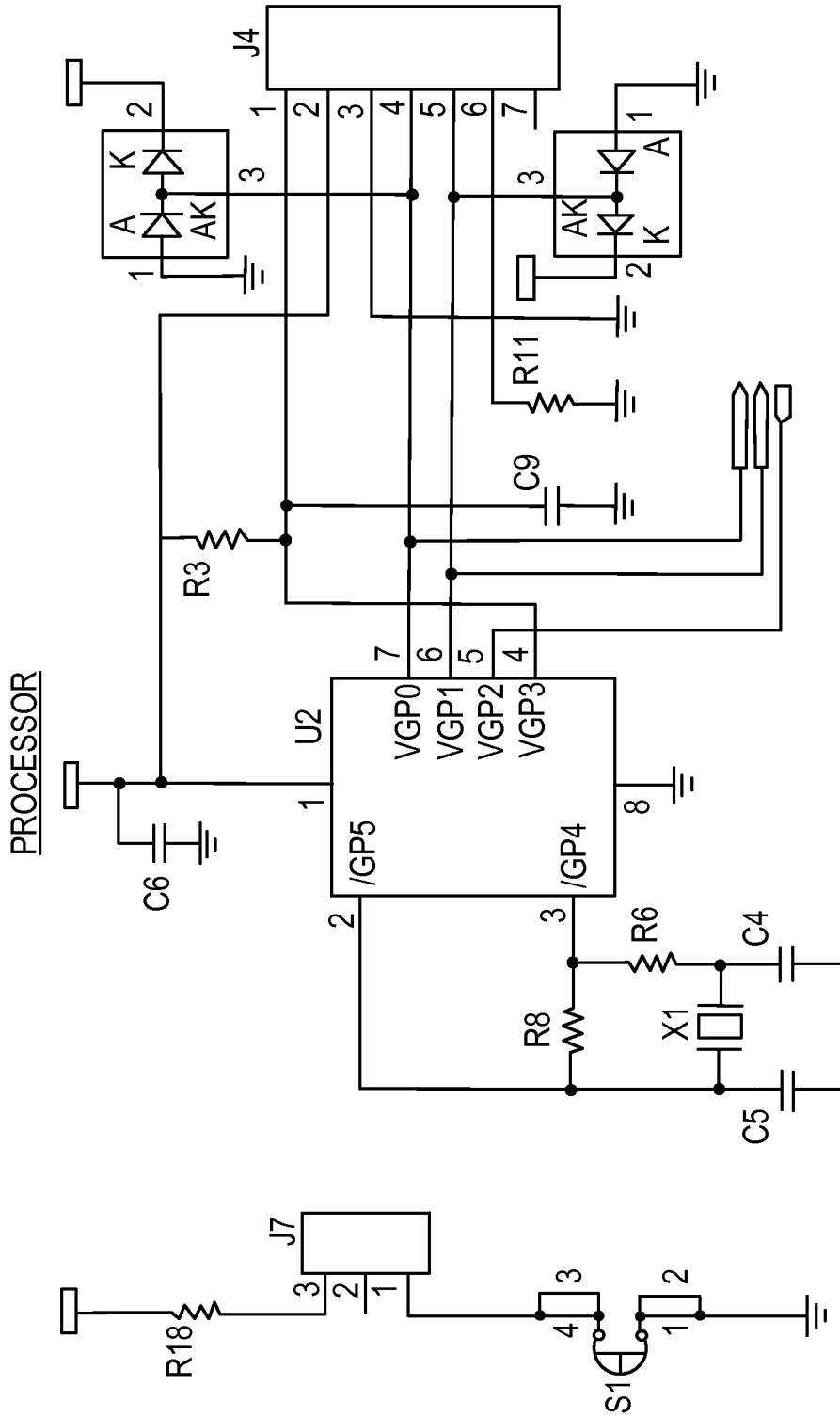

J4
K
A
AK
R11
C9
R3
PROCESSOR
U2
VGP0
VGP1
VGP2
VGP3
/GP5
/GP4
C6
R6
C4
R8
X1
C5
J7
R18
S1

FIG. 8

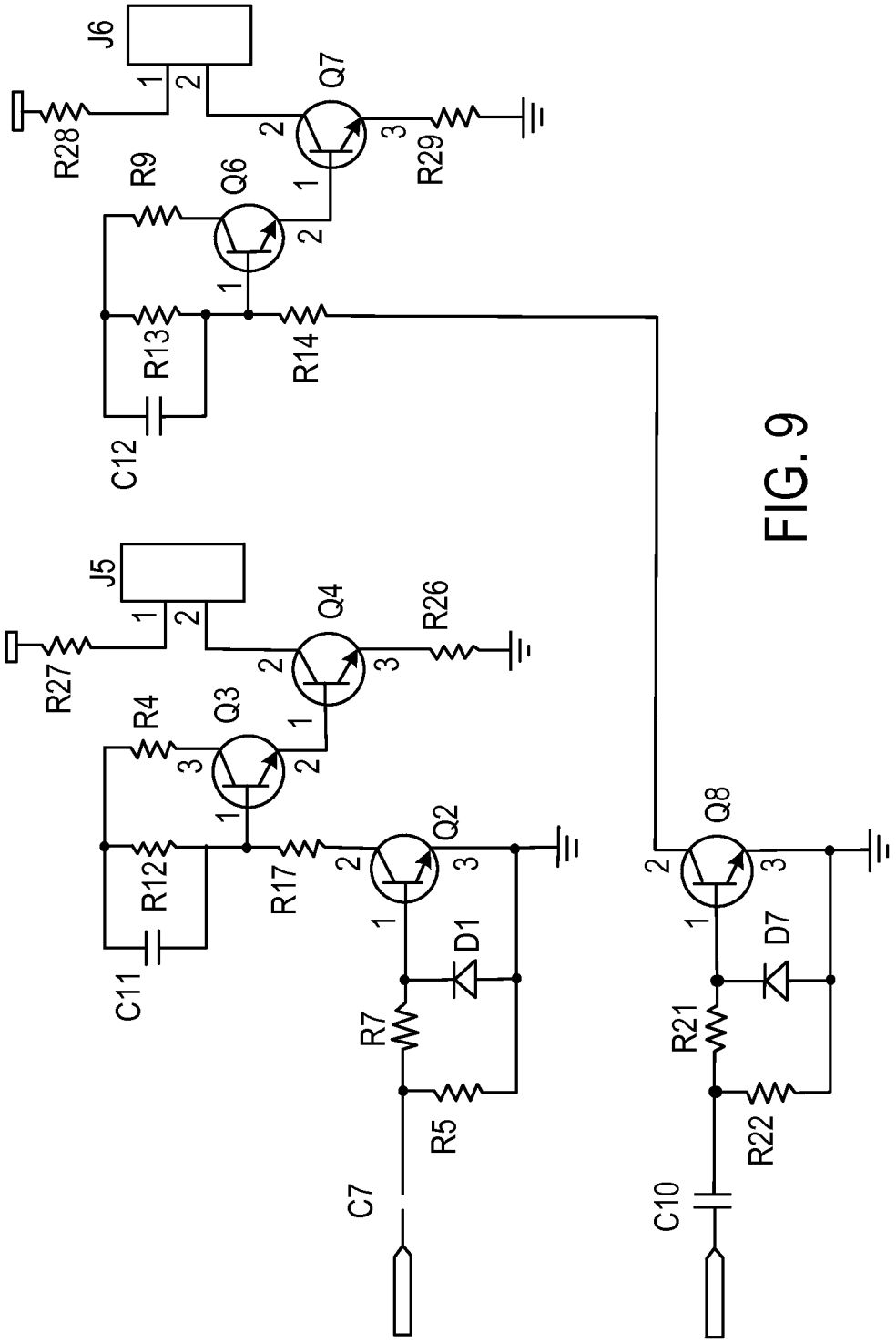

J6
J5
R28
R27
R9
R4
Q6
Q3
Q7
Q4
Q2
Q8
R29
R26
R13
R12
R14
R17
C12
C11
C7
C10
R7
R5
R21
R22
D1
D7

FIG. 9

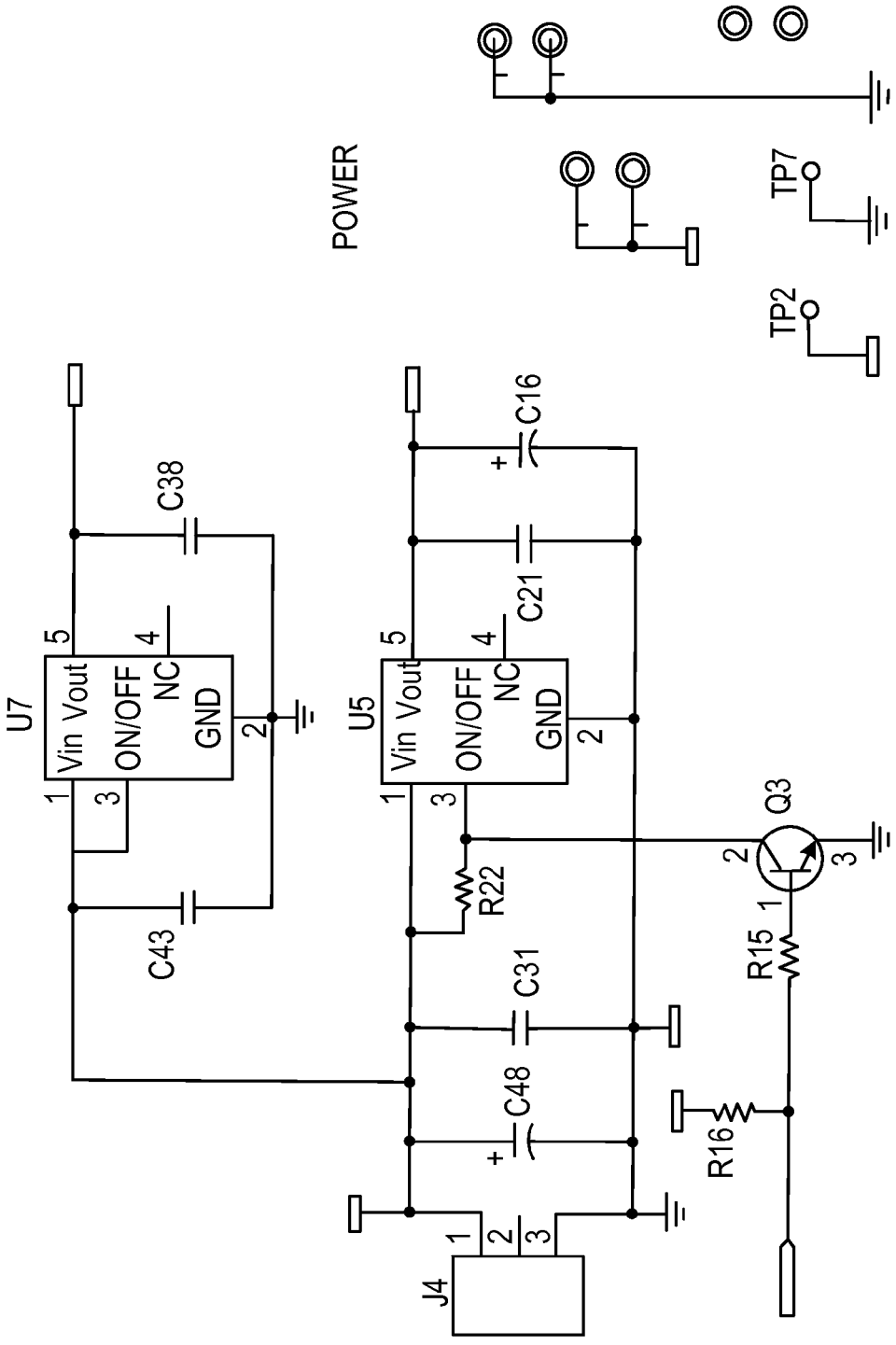

POWER
TP7
TP2
U7
Vin Vout
ON/OFF
NC
GND
C38
C43
U5
C16
C21
C31
C48
R22
R15
R16
Q3
J4

FIG. 10

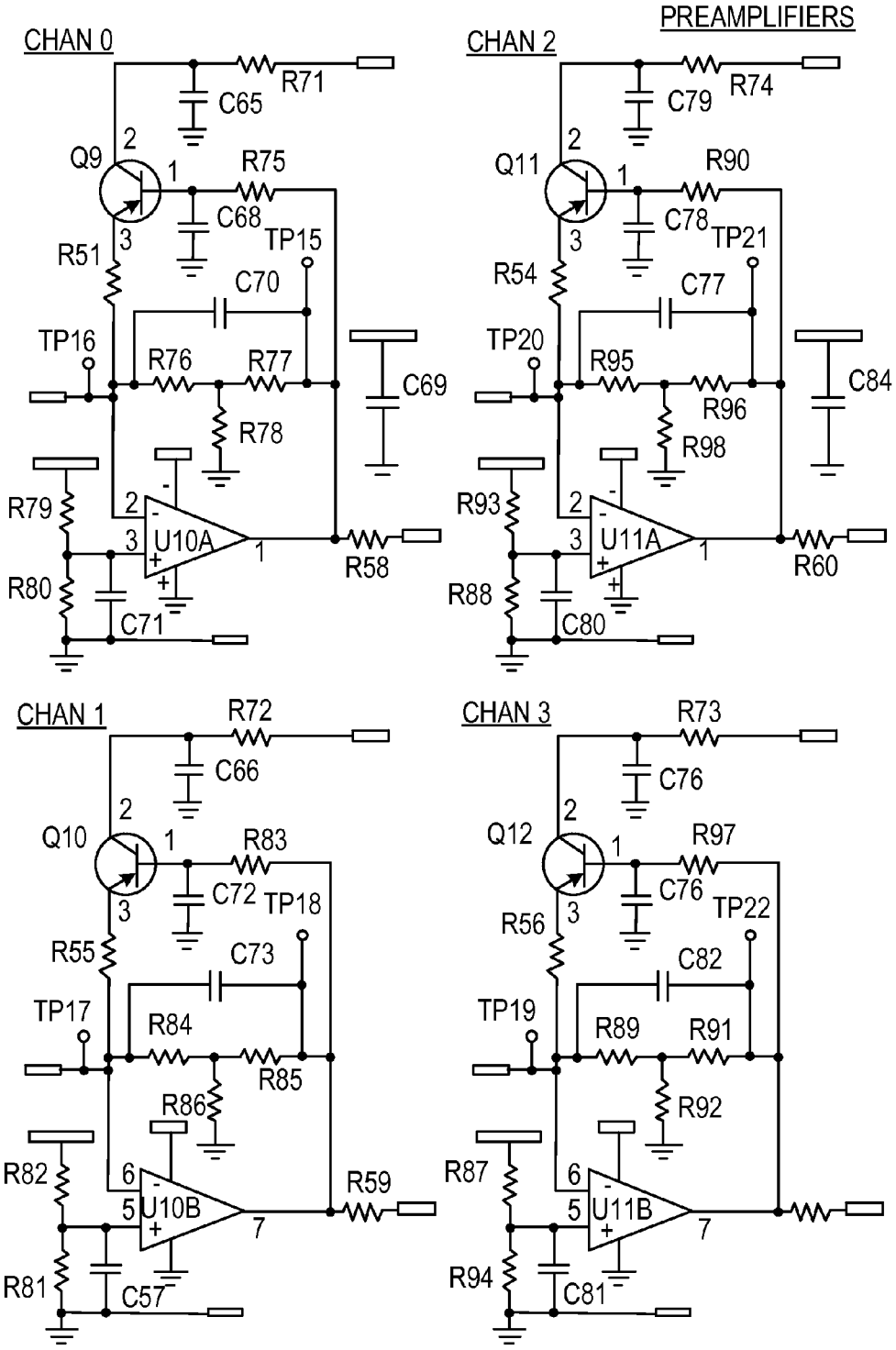

PREAMPLIFIERS
CHAN 0
R71
C65
Q9
R75
C68
TP15
R51
C70
TP16
R76
R77
C69
R78
R79
U10A
R58
R80
C71
CHAN 2
C79
R74
Q11
R90
C78
TP21
R54
C77
TP20
R95
C84
R96
R98
R93
U11A
R60
R88
C80
CHAN 1
R72
C66
Q10
R83
C72
TP18
R55
C73
TP17
R84
R85
R86
R82
U10B
R59
R81
C57
CHAN 3
R73
C76
Q12
R97
C76
TP22
R56
C82
TP19
R89
R91
R92
R87
U11B
R94
C81

FIG. 11A

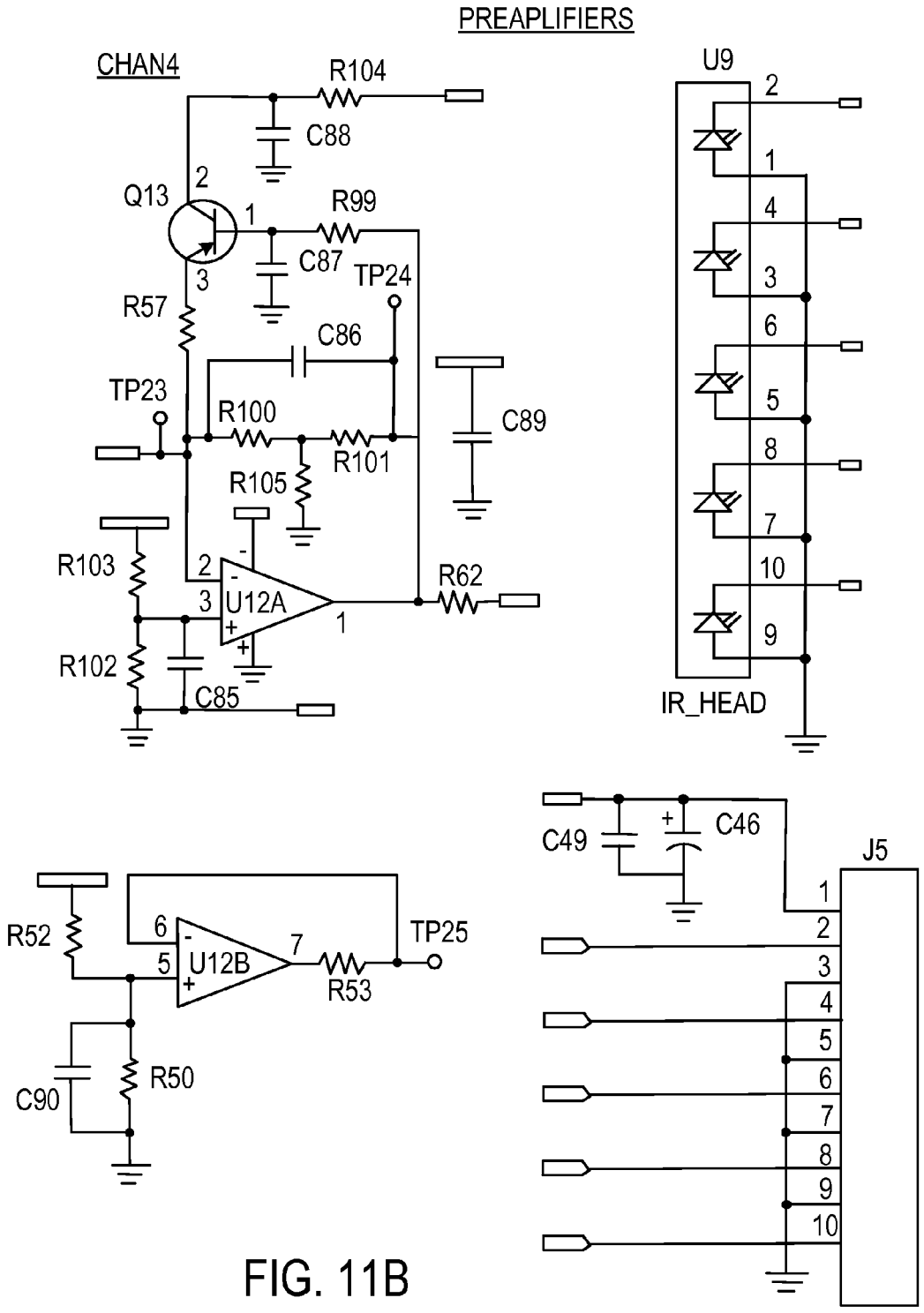

PREAPLIFIERS
CHAN4
R104
C88
Q13
R99
C87
TP24
R57
C86
TP23
R100
R101
C89
R105
R103
U12A
R62
R102
C85
U9
IR_HEAD
R52
U12B
TP25
R53
C90
R50
C49
C46
J5

FIG. 11B

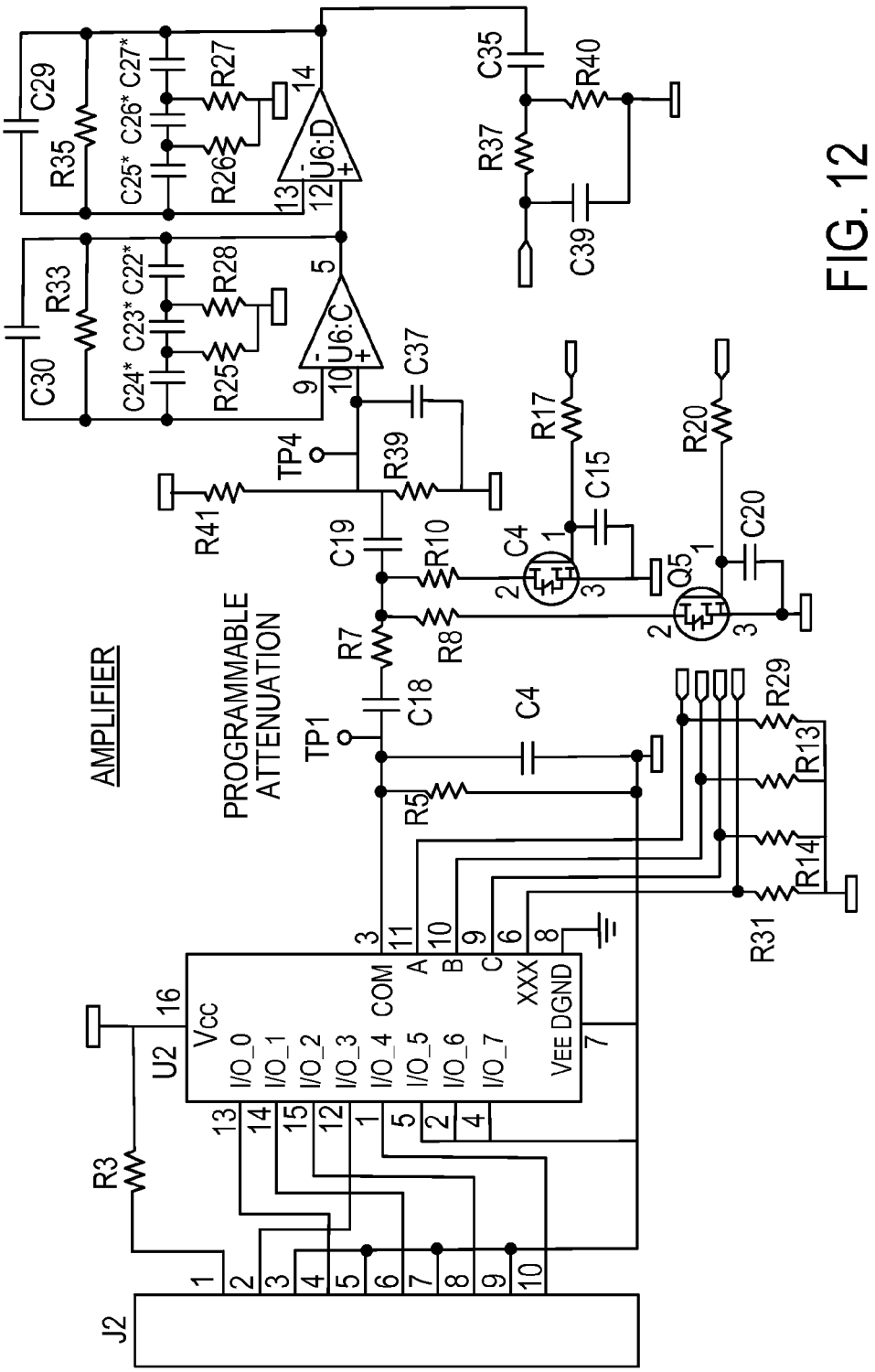
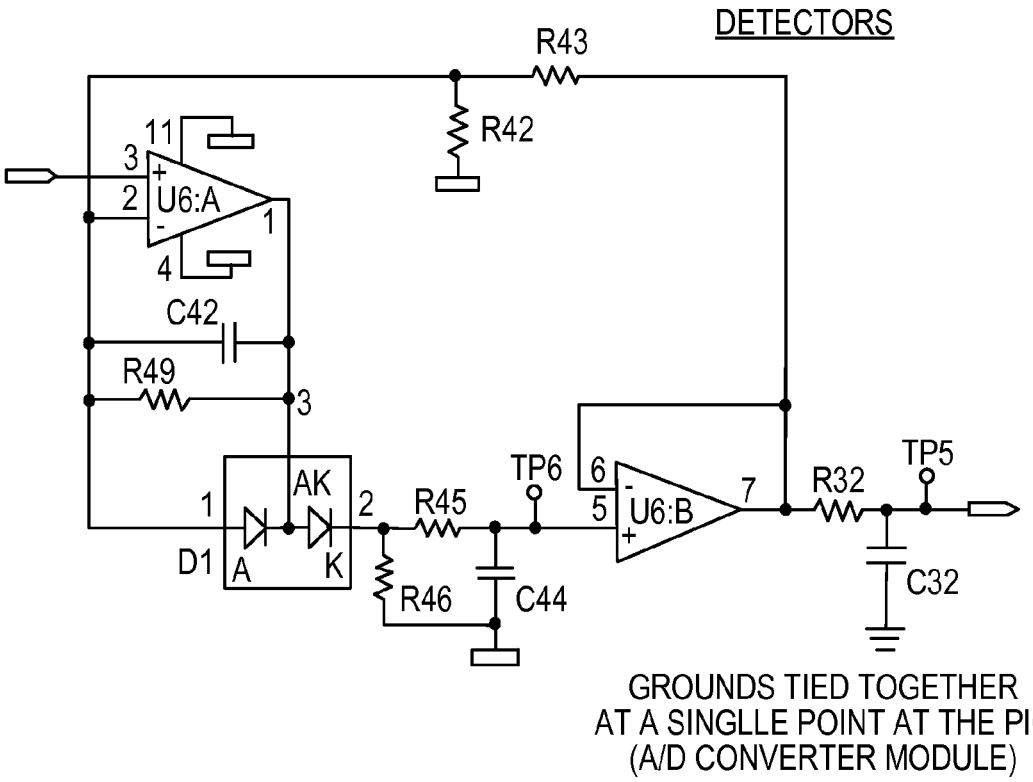

AMPLIFIER
PROGRAMMABLE ATTENUATION
J2
U2
U6:C
U6:D
Vcc
VEE
DGND
COM
XXX
I/O_0
I/O_1
I/O_2
I/O_3
I/O_4
I/O_5
I/O_6
I/O_7
A
B
C
R3
R5
R7
R8
R10
R13
R14
R17
R20
R25
R26
R27
R28
R29
R31
R33
R35
R37
R39
R40
R41
C4
C15
C18
C19
C20
C22*
C23*
C24*
C25*
C26*
C27*
C29
C30
C35
C37
C39
Q5
TP1
TP4

FIG. 12


DETECTORS
R43
R42
11
3
2
U6:A
1
4
C42
R49
3
AK
1
2
D1
A
K
R45
TP6
6
5
U6:B
7
R32
TP5
C32
R46
C44
GROUNDS TIED TOGETHER
AT A SINGLLE POINT AT THE PIC
(A/D CONVERTER MODULE)

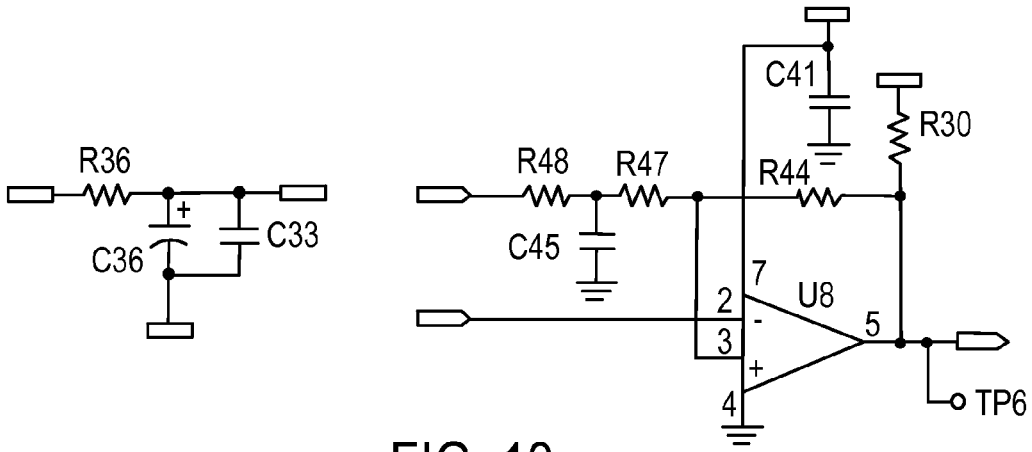

R36
C36
C33
C41
R30
R48
R47
R44
C45
7
2
3
U8
5
4
TP6

FIG. 13

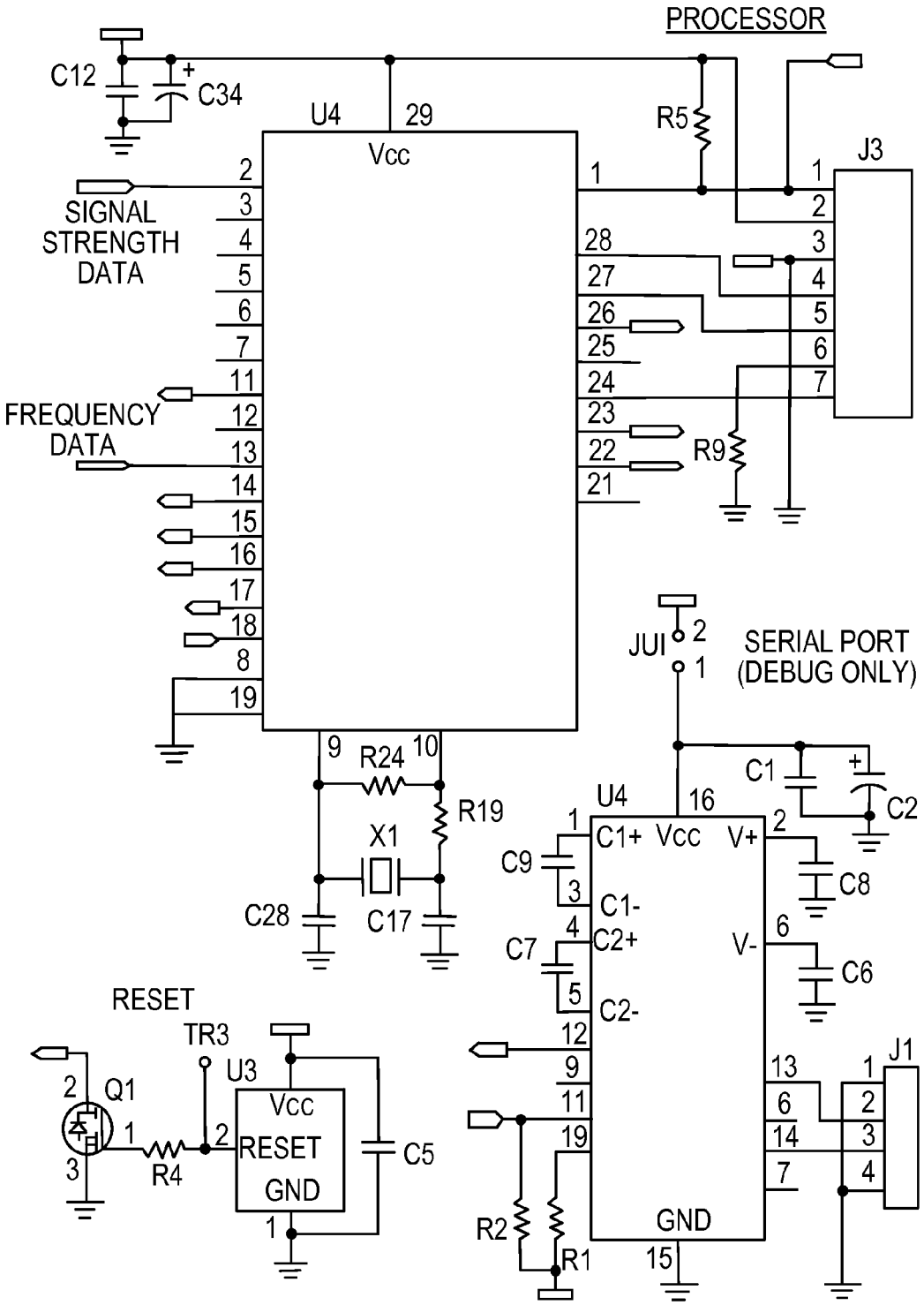

PROCESSOR
C12
C34
U4
29
Vcc
R5
J3
SIGNAL STRENGTH DATA
FREQUENCY DATA
R9
JUI
SERIAL PORT (DEBUG ONLY)
R24
R19
X1
C28
C17
C1
C2
C9
C8
C7
C6
C1+
Vcc
V+
C1-
C2+
V-
C2-
RESET
TR3
U3
Q1
R4
RESET
GND
C5
J1
R2
R1
GND

FIG. 14

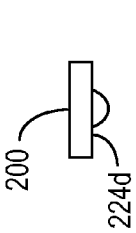


FIG. 15C

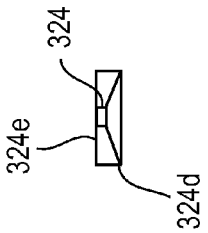


FIG. 16C

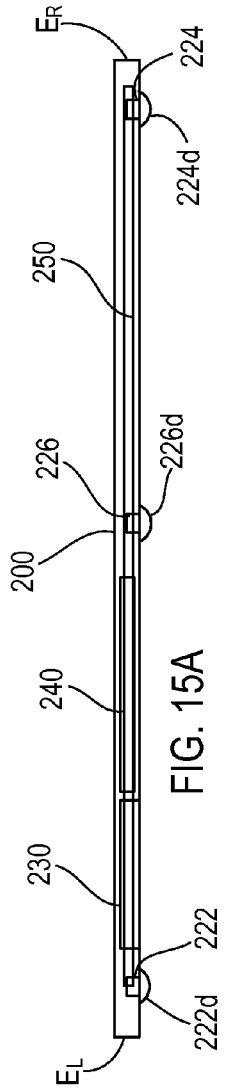


FIG. 15A

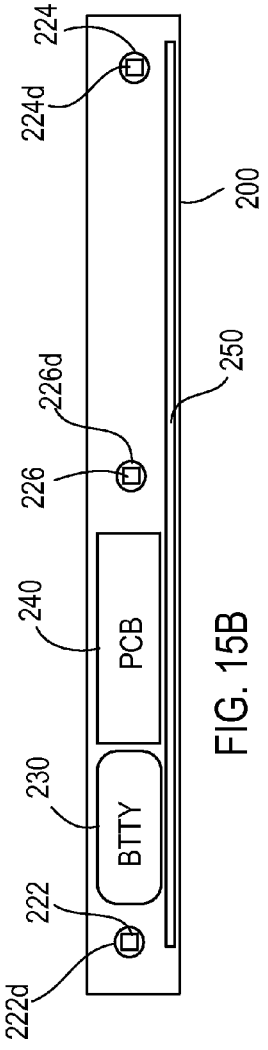


FIG. 15B

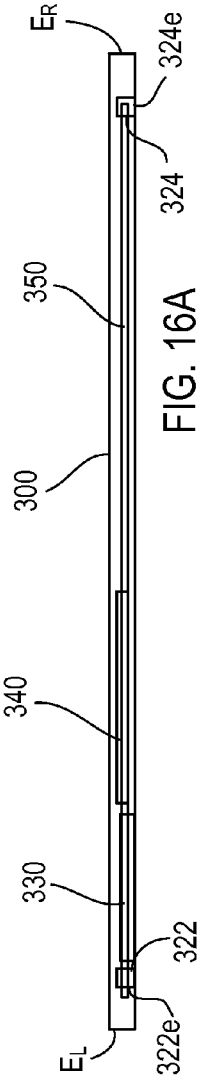


FIG. 16A

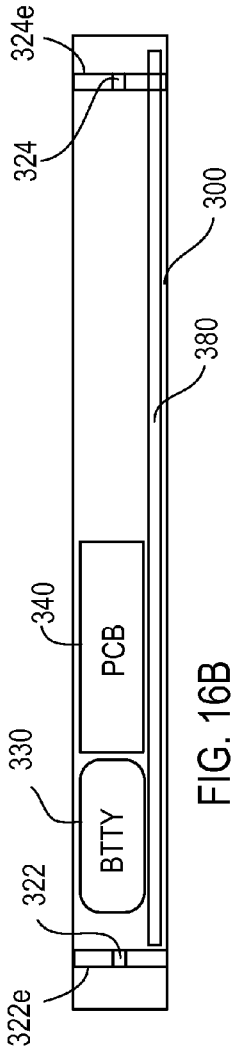


FIG. 16B

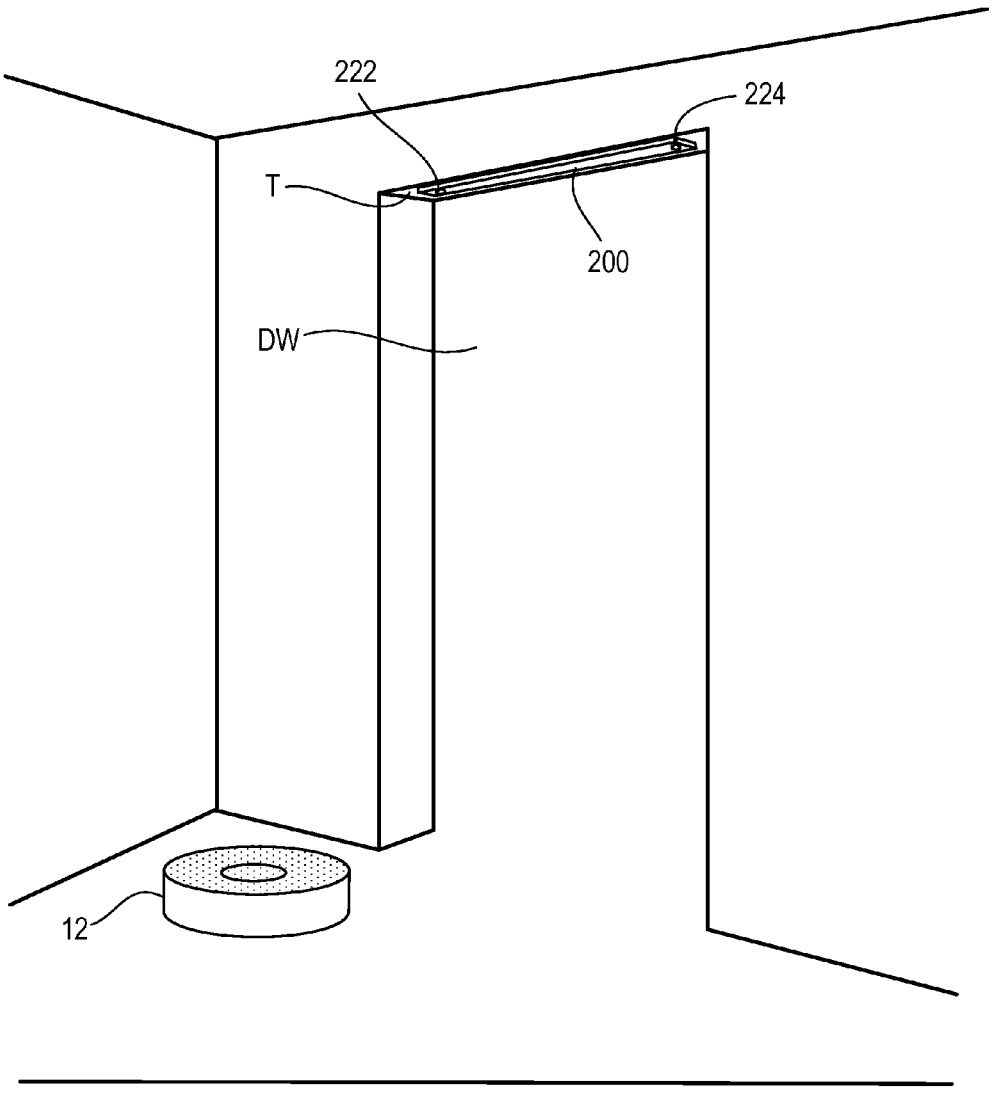


FIG. 17

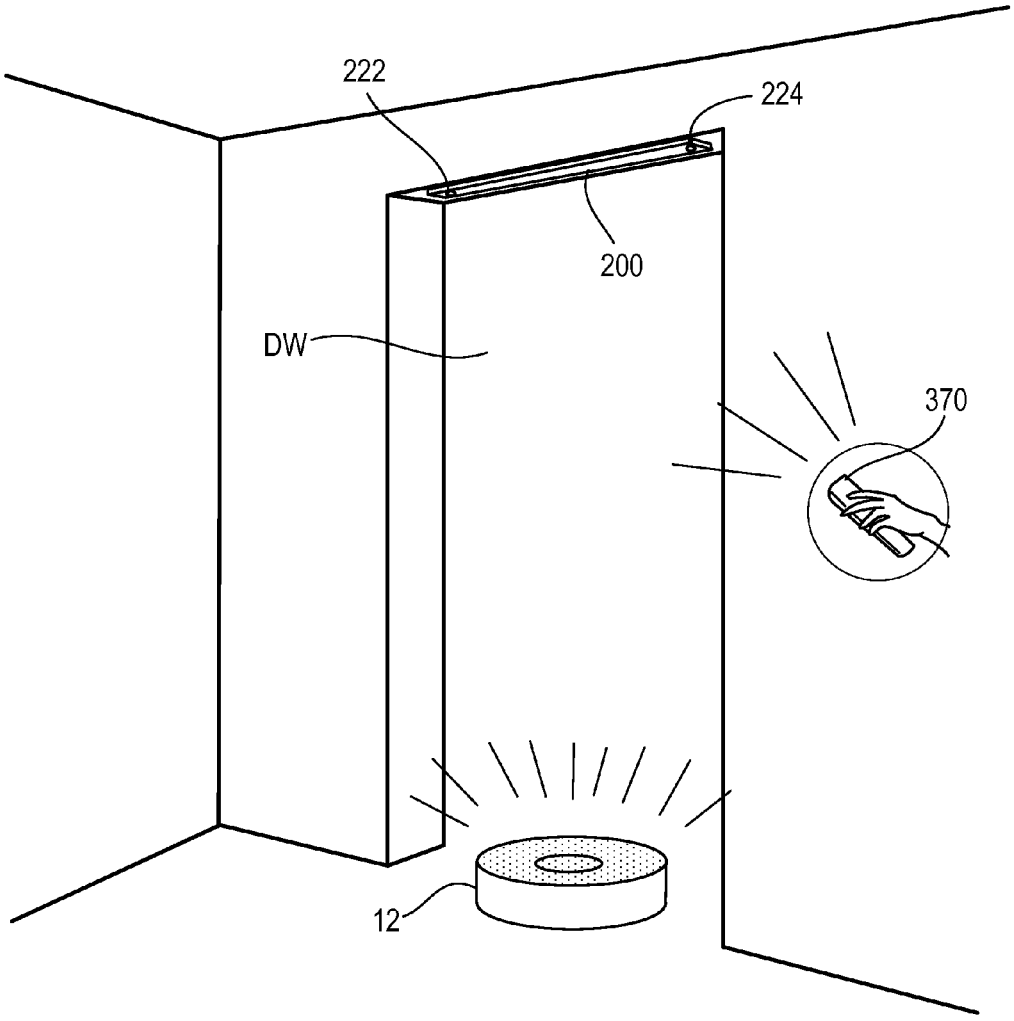


FIG. 18

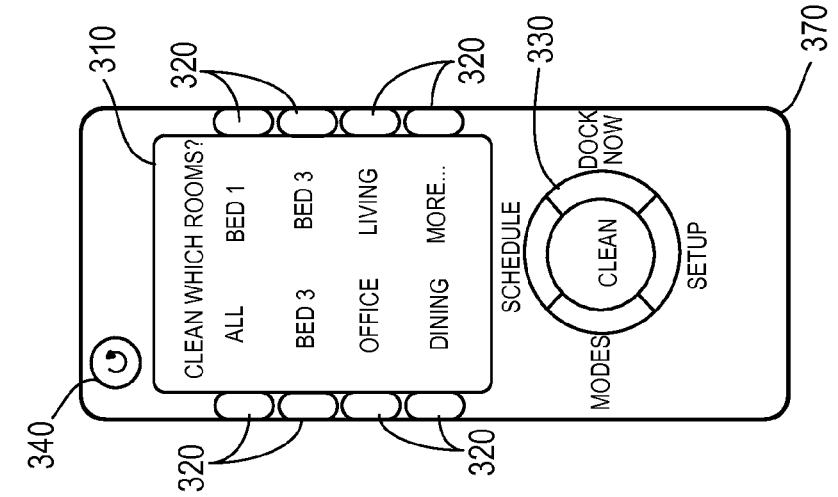


FIG. 19C

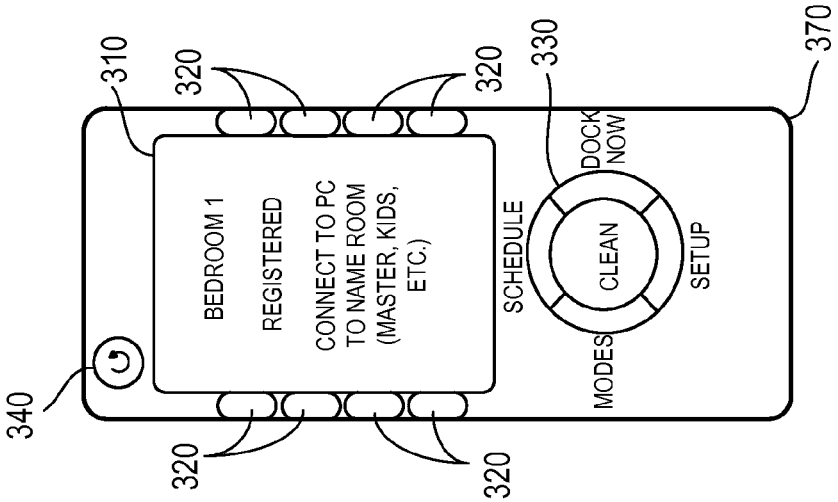


FIG. 19B

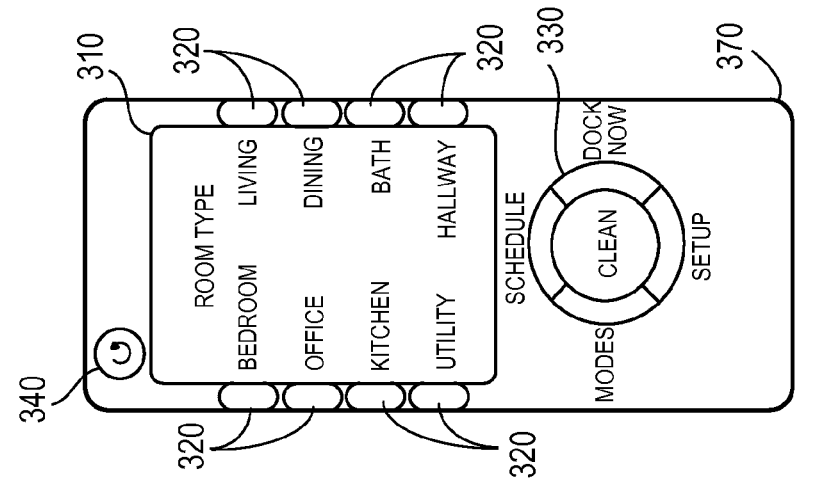


FIG. 19A

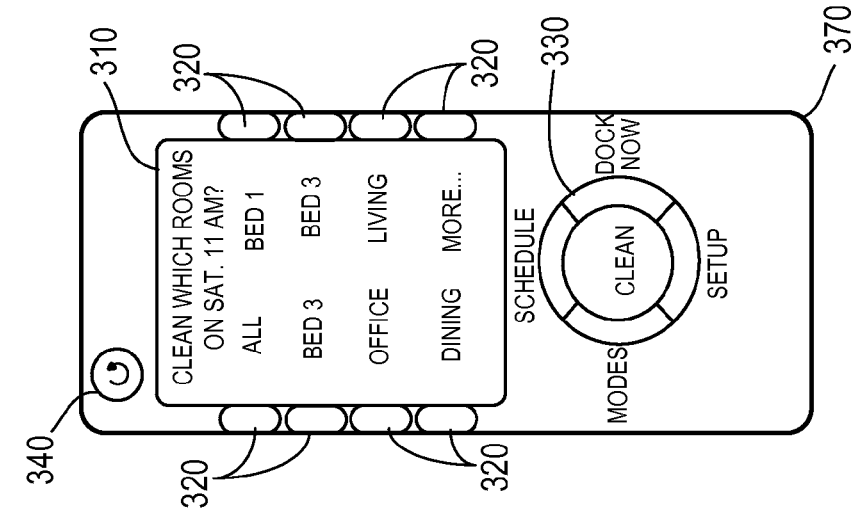


FIG. 20C

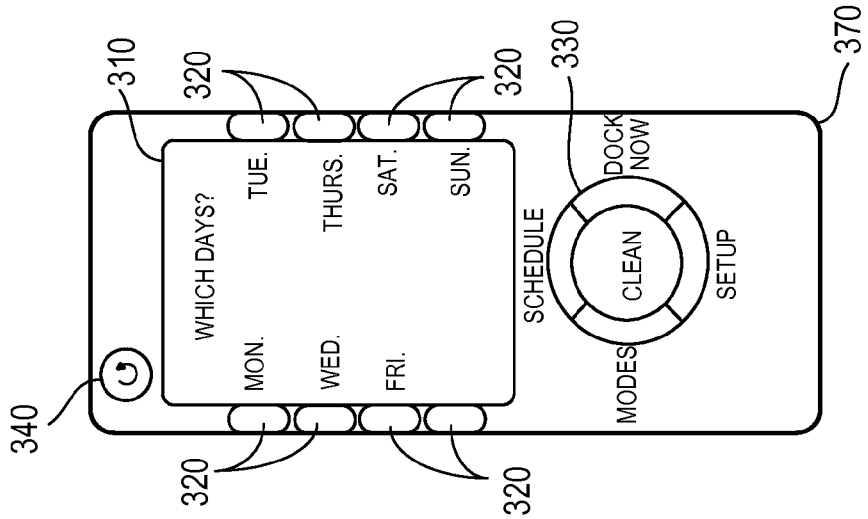


FIG. 20B

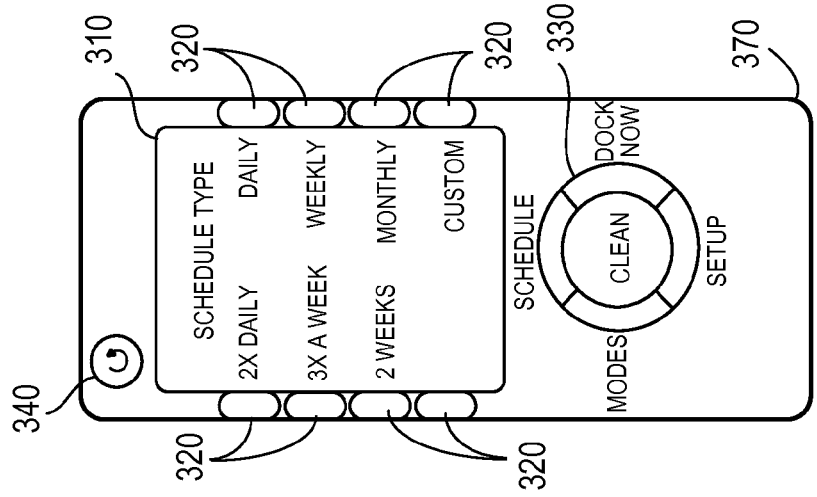


FIG. 20A

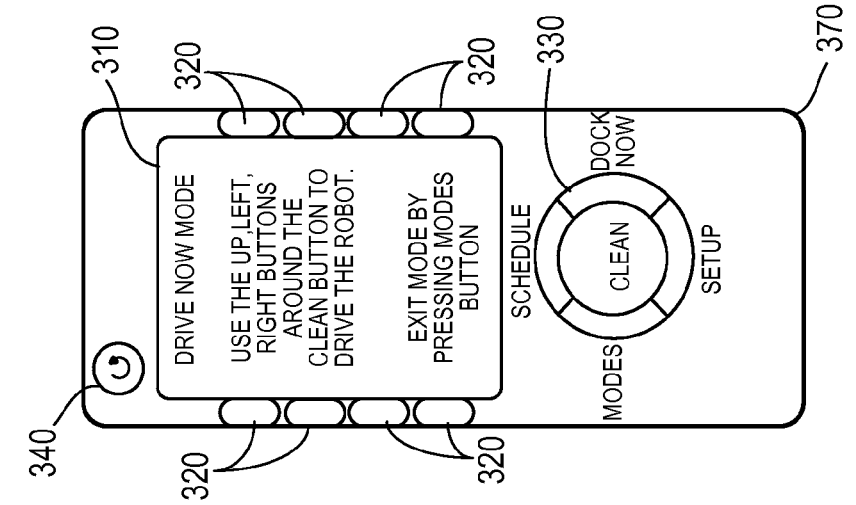


FIG. 21C

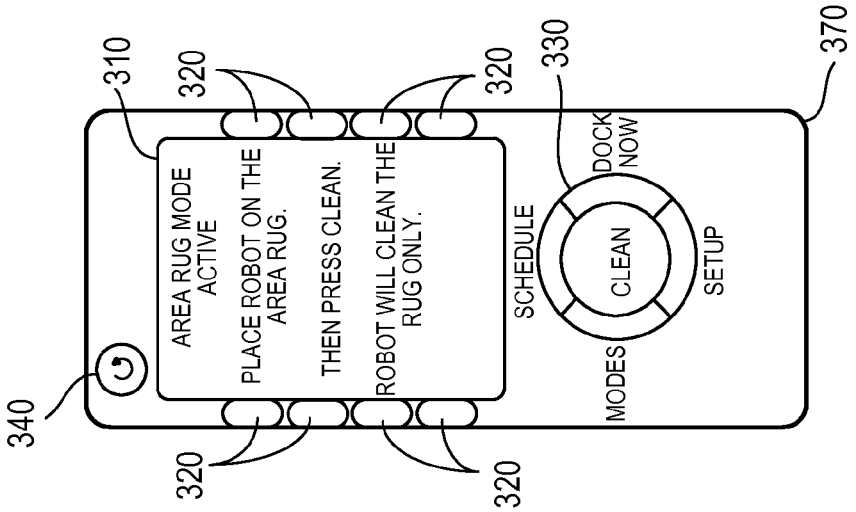


FIG. 21B

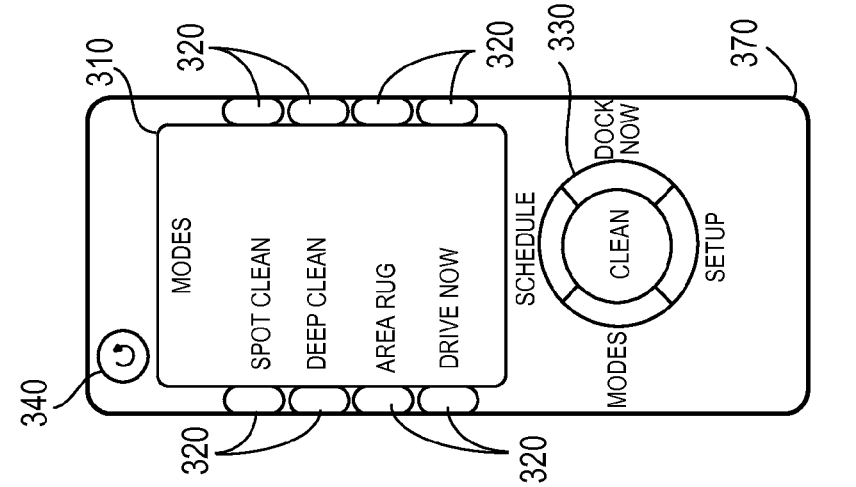


FIG. 21A

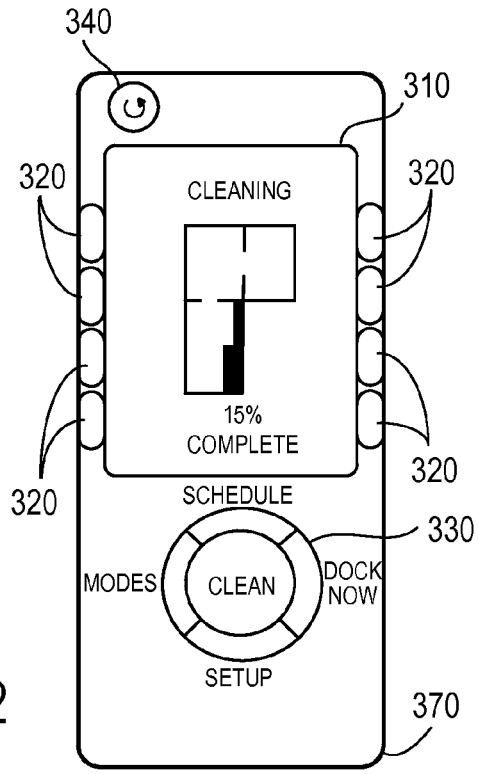

340
310
320
320
CLEANING
15%
COMPLETE
320
320
SCHEDULE
330
MODES
CLEAN
DOCK
NOW
SETUP
370

FIG. 22

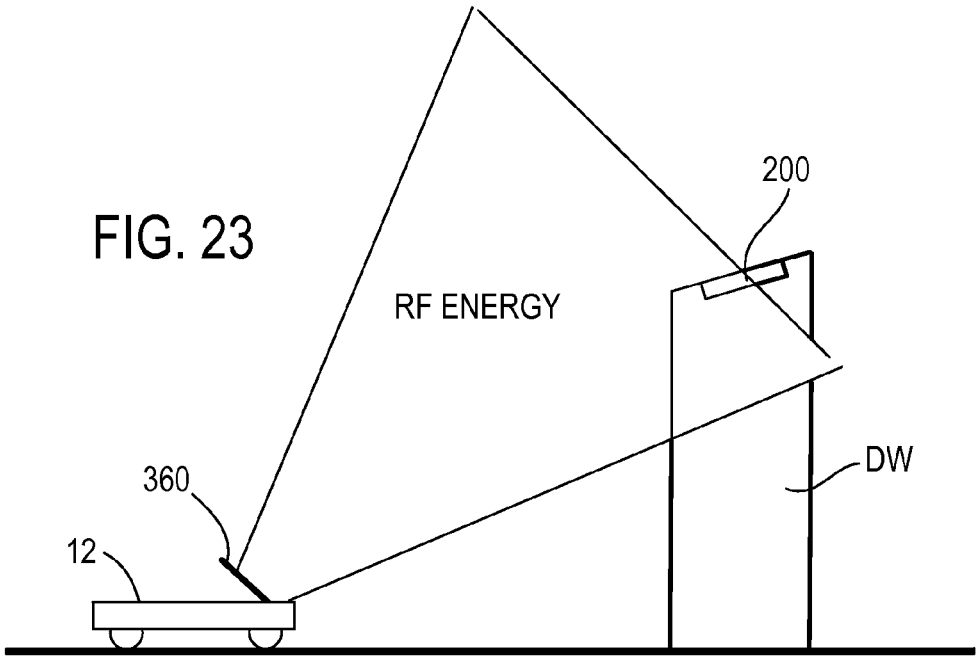

200
RF ENERGY
DW
360
12

FIG. 23

CELESTIAL NAVIGATION SYSTEM FOR AN AUTONOMOUS VEHICLE

CROSS REFERENCE TO RELATED APPLICATIONS

This application is a continuation (and claims the benefit of priority under 35 USC 120) of U.S. application serial no. U.S. application Ser. No. 12/611,814 filed Nov. 3, 2009, which is a continuation-in-part of U.S. application Ser. No. 12/415,554 filed Mar. 31, 2009, and U.S. application Ser. No. 12/415,512 filed Mar. 31, 2009, both of which are continuations of U.S. application Ser. No. 11/176,048 filed Jul. 7, 2005, which claims priority of U.S. provisional application Ser. No. 60/586,046 filed Jul. 7, 2004. The disclosures of all prior applications are considered part of (and are incorporated by reference in) the disclosure of this application.

The present teachings relate to robotic systems and, more specifically, to navigation systems for autonomous vehicles.

BACKGROUND

Autonomous vehicles including robotic devices are becoming more prevalent today and are used to perform tasks traditionally considered mundane, time-consuming, or dangerous. As programming technology increases, so does the demand for robotic devices that can navigate around a complex environment or working space with little or no assistance from a human operator.

Autonomous vehicles and associated controls, navigation systems, and other related systems are being developed. For example, U.S. Pat. No. 6,594,844 discloses a Robot Obstacle Detection System, the disclosure of which is hereby incorporated by reference in its entirety. Additional robot control and navigation systems, and other related systems, are disclosed in PCT Published Patent Application No. WO 2004/025947 and in U.S. Pat. Nos. 6,809,490, 6,690,134, 6,781,338, 7,024,278, 6,883,201, and 7,332,890, the disclosures of which are hereby incorporated by reference in their entireties.

Many autonomous vehicles navigate a working space by moving randomly until an obstacle is encountered. Generally, these types of vehicles have on-board obstacle detectors, such as bump sensors or similar devices, which register contact with an obstacle. Once contact is made, command routines can direct the autonomous vehicle to move in a direction away from the obstacle. These types of systems, which are useful for obstacle avoidance, are limited in their ability to allow an autonomous vehicle to track its location within a room or other working environment. Other systems, often used in conjunction with bump sensors as described above, use an infrared or other detector to sense the presence of nearby walls, obstacles, or other objects, and either follow the obstacle or direct the vehicle away from it. These systems, however, are also limited in their ability to allow an autonomous vehicle to navigate effectively in a complex environment, as they only allow the vehicle to recognize when objects are in its immediate vicinity.

In more advanced navigation systems, an autonomous vehicle comprises an infrared or other type of transmitter, which directs a series of infrared patterns in horizontal directions around the autonomous vehicle. These patterns can be detected by a stationary receiver placed at or near a boundary of the working space, for example on a wall. A microprocessor can use the information from signals generated by the receiver to calculate where in the working space the autonomous vehicle is located at all times. Using such systems, the vehicle can navigate around an entire area. These systems, however, are best employed in working spaces where few objects are present that may interfere with the dispersed patterns of infrared signals.

Limitations of the above types of navigation systems are, at present, a hurdle to creating a highly independent autonomous vehicle that can navigate in a complex environment.

SUMMARY

The present teachings provide a navigation control system for an autonomous vehicle. The system comprises a transmitter and an autonomous vehicle. The transmitter comprises an emitter for emitting at least one signal, a power source for powering the emitter, a device for capturing wireless energy to charge the power source, and a printed circuit board for converting the captured wireless energy to a form for charging the power source. The autonomous vehicle operates within a working area and comprises a receiver for detecting the at least one signal emitted by the emitter, and a processor for determining a relative location of the autonomous vehicle within the working area based on the signal emitted by the emitter.

The present teachings also provide a transmitter for use in a navigation control system for an autonomous vehicle. The transmitter comprises an emitter for emitting at least one signal, a power source for powering the emitter, a device for capturing wireless energy to charge the power source and a printed circuit board for converting the captured wireless energy to a form for charging the power source.

The present teachings further provide a method for controlling navigation of an autonomous vehicle within one or more work areas. The method comprises emitting one or more signals from a transmitter, receiving the one or more signals on the autonomous vehicle, powering the transmitter with a power source, charging the power source wirelessly, localizing the autonomous vehicle with respect to the transmitter, and navigating the autonomous vehicle within the one or more work areas.

Additional objects and advantages of the present teachings will be set forth in part in the description which follows, and in part will be obvious from the description, or may be learned by practice of the teachings. The objects and advantages of the present teachings will be realized and attained by means of the elements and combinations particularly pointed out in the appended claims.

It is to be understood that both the foregoing general description and the following detailed description are exemplary and explanatory only and are not restrictive of the present teachings, as claimed.

The accompanying drawings, which are incorporated in and constitute a part of this specification, illustrate several embodiments of the present teachings and together with the description, serve to explain the principles of the present teachings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a schematic view of a navigation system for an autonomous vehicle in accordance with an exemplary embodiment of the present teachings.

FIG. **2** is a schematic view of a navigation system for an autonomous vehicle in accordance with another exemplary embodiment of the present teachings.

FIG. **3**A is a side view of a stationary emitter in accordance with an exemplary embodiment of the present teachings.

FIG. **3**B is a side view of a stationary emitter in accordance with another exemplary embodiment of the present teachings.

FIG. **4**A is a side view of an infrared receiver for an autonomous vehicle in accordance with an exemplary embodiment of the present teachings.

FIG. **4**B is a top view of the infrared receiver of FIG. **4**A.

FIG. **4**C is a side view of an infrared receiver for an autonomous vehicle in accordance with another exemplary embodiment of the present teachings.

FIG. **5**A illustrates a control system for an infrared receiver for an autonomous vehicle in accordance with an exemplary embodiment of the present teachings.

FIG. **5**B is a flowchart of a signal detection and localization program in accordance with an exemplary embodiment of the present teachings.

FIG. **6** is a top view of a navigation system for an autonomous vehicle in accordance with another exemplary embodiment of the present teachings.

FIGS. **7-14** are schematic circuit diagrams of infrared receivers and transmitters for a navigation system in accordance with an exemplary embodiment of the present teachings.

FIGS. **15**A-**15**C illustrate side, bottom, and end views, respectively, of an exemplary embodiment of a transmitter in accordance with the present teachings.

FIGS. **16**A-**16**C illustrate side, bottom, and end views, respectively, of another exemplary embodiment of a transmitter in accordance with the present teachings.

FIG. **17** illustrates the transmitter of FIGS. **15**A-**15**C used in a doorway.

FIG. **18** also illustrates the transmitter of FIGS. **15**A-**15**C used in a doorway.

FIGS. **19**A-**19**C illustrate exemplary embodiments of setup screens on an exemplary remote control in accordance with the present teachings.

FIGS. **20**A-**20**C illustrate exemplary embodiments of schedule screens on an exemplary remote control in accordance with the present teachings.

FIGS. **21**A-**21**C illustrate exemplary embodiments of mode screen on an exemplary remote control in accordance with the present teachings.

FIG. **22** illustrates exemplary embodiments of a status screen on an exemplary remote control in accordance with the present teachings.

FIG. **23** schematically illustrates an embodiment of a system in accordance with the present teachings.

DESCRIPTION OF THE PRESENT TEACHINGS

Reference will now be made in detail to embodiments of the present teachings, examples of which are illustrated in the accompanying drawings. Wherever possible, the same reference numbers will be used throughout the drawings to refer to the same or like parts.

In accordance with an exemplary implementation of the present teachings, FIG. **1** is a schematic view of a navigation system **10** for an autonomous vehicle such as a robotic cleaning device **12**. The components of the system **10** include, in this embodiment, a transmitter **20**, a charging or base station **22**, and an autonomous vehicle **12** that operates in a room or other similar working area **14**. The working area **14** can be a floor of a room, bounded at least in part by walls **16**. Borders of a ceiling **18** intersect the walls **16** and are remote from the working area **14**. The depicted transmitter **20** includes two emitters **24**A, **24**B. In this exemplary embodiment, the base station **22** includes an emitter **26** as well. In various embodiments, any combination or quantity of emitters may be used on the base station **22**, or transmitter **20**, or both. The autonomous vehicle **12** can include an on-board microprocessor, power and drive components, task-specific components (dirt sensors, vacuums, brushes, etc.), and at least one receiver, such as an infrared receiver **28**. The vehicle **12** may also include certain buttons, switches, etc. for programming the robot, or such instructions may be directed by a remote control (see FIG. **18**) or a personal computer (not shown). Depending on the application, certain components may be removed from the disclosed system **10**, or other components may be added.

For simplicity, this disclosure will describe vacuuming as a demonstrative task of the depicted robotic cleaning device **12**. It will be apparent, though, that the navigation system disclosed herein has wide applications across a variety of autonomous systems. For example, an autonomous vehicle may be used for floor waxing and polishing, floor scrubbing, ice resurfacing, sweeping and vacuuming, unfinished floor sanding, stain/paint application, ice melting and snow removal, grass cutting, etc. Any number of task-specific components may be required for such duties, and may each be incorporated into the autonomous vehicle, as necessary.

The transmitter **20** directs at least two infrared signals **22***a*, **24***a* from emitters **24**A and **24**B to a surface remote from the working area **14** upon which the autonomous vehicle **12** operates. The depicted embodiment directs the infrared signals **22***a*, **24***a* to the ceiling **18**, but it may also direct the signals **22***a*, **24***a* to a portion of a wall **16** or to both the walls **16** and ceiling **18**. The signals **22***a*, **24***a* can be directed to a variety of points on the remote surface, but directing the signals as high as possible above the working area **14** can allow the signals **22***a*, **24***a* to be more easily detected by the autonomous vehicle **12**, because the field of view of the autonomous vehicle's receiver **28** is less likely to be blocked by an obstacle (such as, for example, a high-backed chair or tall plant). In this disclosure, the regions of contact **22***b*, **24***b* of the signals **22***a*, **24***a* on the remote surface will be referred to as "points," regardless of the size of the intersection. For example, by using a collimator in conjunction with the emitters (described below), the points of intersection **22***b*, **24***b* of the signals **22***a*, **24***a* can be a finite area with the signal strongest at approximately central points.

In certain embodiments of the transmitter **20**, the signals **22***a*, **24***a* are directed toward a ceiling **18**, at two points **22***c*, **24***c*, forming a line proximate and parallel to the wall **16** upon which the transmitter **20** is located. Alternatively, and as depicted in FIG. **1**, the signals **22***a*, **24***a* can be directed away from the wall **16**, at an angle of approximately 5° or more, to avoid interference with objects such as pictures secured to or hung from the wall **16**. The signals **22***a*, **24***a* can be transmitted at a known angle θ therebetween. In an exemplary embodiment, angle θ can equal approximately 30°, but other angles are contemplated by the present teachings. In accordance with certain embodiments, angle θ can be set at the time of manufacture or user-defined based on particular applications or other requirements. By setting the angle θ to a known value, the distance S between the signals **22***a*, **24***a* at the point of contact **22***c*, **24***c* with ceiling **18** may be determined, provided the heights of the ceiling h_1, h_2 at the points of contact **22***c*, **24***c* are known. When used on a flat ceiling **18**, as depicted, h_1 equals h_2. In the embodiment depicted in FIG. **1**, base station **22** emits a signal **26***a* that can serve as an additional or optional signal for utilization by the autonomous vehicle **12**. Signal **26***a* is directed toward a wall **16**, so that the point of contact **26***b* is high enough to avoid objects that may obstruct the autonomous vehicle's field of view. A central point **26***c* (or laser point) of the point of contact **26***b* contacts the wall **16** at height h**3**.

As the autonomous vehicle **12** moves within a working area **14**, it detects the signals **22***a*, **24***a* emitted by the transmitter **20** as energy bouncing or reflecting off of the diffuse ceiling surface **18**. In an alternative embodiment, visible points can be used in place of infrared points. A camera onboard the autonomous vehicle can replace the infrared receiver in detecting either infrared or visible points. The autonomous vehicle's microprocessor can convert the signals **22***a*, **24***a* sensed by the receiver **28** into bearings from the robot **12** to the signals **22***a*, **24***a*. The microprocessor can then calculate representative elevation angles ϵ_1, ϵ_2 and azimuths α_1, α_2 of the signals to determine the location of the autonomous vehicle **12** within the working area **14**. In this embodiment, the azimuths α_1, α_2 are measured using a "forward" direction of movement M of the autonomous vehicle **12** as a datum, but any suitable datum can be used. By calculating the elevation angle and azimuth from the autonomous vehicle **12** to the two signals **22***a*, **24***a*, the autonomous vehicle **12** can locate itself within a working area with improved accuracy.

FIG. **2** depicts another exemplary embodiment of a navigation system **110** for an autonomous vehicle **112**. In the illustrated exemplary embodiment, an autonomous vehicle **112** moves in a working area having a floor **114**. A transmitter **120** can be mounted at a top frame of a doorway **132** between two rooms **136**, **138**. Similar to the embodiment depicted in FIG. **1**, the transmitter **120** is installed at a known distance h_4 above the floor **114**. In alternative embodiments, the transmitter **120** can be installed at the height of the ceiling **118**. The transmitter **120** can be recessed within the door frame **130** or ceiling **118** to reduce its profile and limit its impact on architectural aesthetics of a room. Additionally, the transmitter **120** can be disguised to resemble a cover plate for a sprinkler head, speaker, or other device.

The transmitter **120** emits two signals **122***a*, **124***a* (depicted graphically by a plurality of arrows) into the two rooms **136**, **138**, respectively. The signals **122***a*, **124***a* can be configured to not overlap each other, thus providing a distinct signal on each side of the door centerline **130**. In other embodiments, an overlap of the signals **122***a*, **124***a* can be desirable. The autonomous vehicle **112** includes a receiver **128** having a field of vision **134**. The emitted signals **122***a*, **124***a* can be detected by the receiver **128** when the autonomous vehicle's field of vision **134** intersects the signals **122***a*, **124***a*. Similar to the embodiment of FIG. **1**, the autonomous vehicle can calculate the azimuth and elevation to the transmitter **120** to determine its relative location. Similar to the embodiment described above, by detecting only one signal, the autonomous vehicle **112** can calculate a bearing to the transmitter **120**. Accordingly, the transmitter **120** functions as a beacon for the autonomous vehicle **112** to follow and, if the signal is coded, the autonomous vehicle **112** can determine which room of a number of rooms it is located in, based on the coded signal. The autonomous vehicle **112** is thus able to determine its relative location on a room-by-room basis, as opposed to determining its location within a room. Exemplary embodiments of a doorway-based transmitter are described in more detail with reference to FIGS. **15-18**.

FIG. **3**A shows a transmitter **20** in accordance with certain embodiments of the present teachings. The depicted transmitter **20** receives power from a wall outlet **40** for convenience and unobtrusiveness, but one skilled in the art will appreciate that transmitters can be powered by means other than a wall outlet. For example, the transmitter can be placed anywhere in a room, provided it has an available power source. For example, battery-powered transmitters are particularly versatile, because they can be located remote from a wall outlet. Such battery-operated transmitters can be unobtrusively located above window or door frames, or on top of tall furniture such as dressers or bookshelves.

In accordance with various embodiments of the present teachings, the transmitter can include a visible signal option (not shown), aligned with the emitted signals, allowing a user to direct the signals to particular locations. In accordance with the present teachings, more than one transmitter maybe used. Such a system could include communication capability between the various transmitters, for example to ensure that only one signal or a subset of signals is emitted at any given time.

A battery-powered transmitter located above a window or door frame can not only permit the autonomous vehicle to localize within a map, coordinate system, or cell grid relative to the transmitter, but can also localize the transmitter within the same map, coordinate system, or cell grid, thereby localizing the window or door frame. Localization of an autonomous vehicle within a working environment is described in detail in U.S. Patent Publication No. 2008/0294288, filed Nov. 27, 2008, the entire disclosure of which is incorporated herein by reference. In the case of a door frame, the door is ordinarily the passage by which the autonomous vehicle navigates from room to room. The transmitter illustrated in FIG. **3**A, which can project points upward onto a wall or ceiling, can be battery operated. A transmitter as illustrated in FIGS. **3**B-**3**D can be placed above or at the top of a door (e.g., more than six feet high, where household power may be unavailable) and can also benefit from battery operation (see below).

The exemplary embodiment of a transmitter **20** illustrated in FIG. **3**A includes a housing **42** constructed of, for example, a plastic or like material. In this figure, the transmitter **20** is shown cut-away above the line L so that the emitters can be seen. The transmitter **20** can include a power receptacle **44**, allowing the outlet used by the transmitter **20** to remain available for other uses. The transmitter **20** includes two emitters **24**A, **24**B, set within the housing **42**. Alternatively, the emitters **24**A, **24**B can be flush with or extend beyond the housing **42**. Setting the emitters **24**A, **24**B within the housing **42** allows the signals **22***a*, **24***a* to be directed by utilizing collimators **22***e*, **24***e*. The collimators **22***e*, **24***e* can be formed within the housing **42** or can be discreet components within the housing **42**. Alternatively, the collimators **22***e*, **24***e* can be secured to the outside of the housing **42**. In alternative embodiments, lenses **22***d*, **24***d* can be included, with or without collimators **22***e*, **24***e*, to focus and direct the signals **22***a*, **24***a*. These basic manufacturing considerations can also be adapted for emitters located on charging or base stations. One or more emitters on a base station can serve as an additional point of navigation for the autonomous vehicle within the room, or may simply aid the autonomous vehicle in locating the base station.

FIG. **3**B depicts an embodiment of a transmitter **120** for use, for example, with the navigation system **110** depicted in FIG. **2**. The transmitter **120** is secured to the underside of an upper cross member of the door frame **132**, but can also be recessed therein or secured to or recessed in a ceiling **118**. The transmitter **120** includes two emitters **122**, **124**. Other embodiments of the transmitter **120** can include more than two emitters or a single emitter. By utilizing two emitters, the transmitter **120** can direct signals into two different rooms, on either side of the centerline **130** of the door frame **132**. This can allow an autonomous vehicle to distinguish which room it is located in.

In accordance with various embodiments of the present teachings, more than two emitters can be utilized with collimators **22***e*, **24***e*, **122***e*, **124***e*, to distinguish different areas within a room. Such a configuration allows the autonomous

vehicle to sense its relative location within a room and adjust its cleaning behavior accordingly. For example, a signal could mark an area of the room that an autonomous vehicle would likely get stuck in. The signal could allow an autonomous vehicle to recognize the area and accordingly not enter it, even though it might otherwise be able to do so unimpeded. Alternatively, or in addition, different signals could mark areas that require different cleaning behaviors (e.g., due to carpeting or wood floors, high traffic areas, etc.).

Turning back to FIG. **3**B the emitters **122**, **124** can be installed flush with or extend beyond the housing **142**. Setting the emitters **122**, **124** within the housing **142** allows the signals **122***a*, **124***a* to be directed by utilizing collimators **122***e*, **124***e*. The collimators **122***e*, **124***e* allow the signals **122***a*, **124***a* to be directed to two sides of a centerline **130** of a doorframe **132**, without any signal overlap, if so desired. The collimators **122***e*, **124***e* can be formed within the housing **142** or can be discreet components within the housing **142**. Alternatively, the collimators **122***e*, **124***e* can be secured to the outside of the housing **142**. In alternative embodiments, lenses **122***d*, **124***d* may be included, with or without collimators **122***e*, **124***e*, to focus and direct the signals **122***a*, **124***a*.

In various embodiments of the present teachings, each signal (regardless of the emitter's location or the number of signals) can be modulated at 10 kHz and coded with an 8-bit code serving as a unique signal identifier, preventing the autonomous vehicle from confusing one signal or point with another. Accordingly, more than two uniquely encoded signals can be employed to increase the accuracy of the autonomous vehicle's calculations regarding its location within a working area. As noted above, using only one emitter allows an autonomous vehicle to take a heading based on that signal. Using two or more signals can allow the autonomous vehicle to continue navigating if fewer than all of the signals are detected (either due to a failure of a signal transmission or the autonomous vehicle moving to a location were fewer than all of the signals are visible).

In certain embodiments, the transmitter can pulse the coded signals as follows. After an initial synchronization pulse, a first signal at 10 kHz is emitted for 100 ms. This can provide a sufficient time for the autonomous vehicle's receiver and processor to calculate azimuth and elevation angles, as discussed in detail below. So that the autonomous vehicle can determine which signal is being received, the transmitter can pulse a series of five bits, each for 10 ms. The five bits include two start bits, for example a zero and a one, followed by a unique three bit identifier to identify that particular signal or point. After a 100 ms delay, the transmitter repeats the sequence for the second signal or point. By changing the modulation frequency and/or the identifier, the second signal or point can be uniquely distinguished from the first. Any number of unique signals can be transmitted and identified in this manner. After the series of signals are transmitted, the transmitter can wait a substantially longer period of time, for example on the order of one to two seconds, before repeating the transmitting sequence, starting again with the first signal. The length of time for each transmission is merely exemplary, and may be varied based on a particular application, device, etc. As stated above, the signals can be modulated at the same or different frequencies.

FIG. **4**A depicts a side view of an exemplary receiver **228** that is surface mounted on a housing **212** of an autonomous vehicle. FIG. **4**B is a top view of the same receiver **228**. The receiver **228** can include an outer shell or housing **244** comprising a generally translucent or transparent, high-impact plastic or like material. Four photodiodes **246***a*, **246***b*, **246***c*, and **246***d* can be installed in an orientation in the housing **244** generally corresponding to four adjacent sides of a cube. Accordingly, each photodiode can be generally perpendicular to the photodiodes on either side of it and parallel to the photodiode opposite it. In certain embodiments, a fifth photodiode **246***e* can be located generally above the plane of orientation of photodiodes **246***a*-**246***d*. At least one photodiode, in this case photodiode **246***a*, is oriented toward a direction of forward movement M of the robot. The photodiodes can be connected via control wiring and other components to the autonomous vehicle's microprocessor and related systems. Installing a receiver **228** on top of the housing **212** can provide the autonomous vehicle with a wide field of view. As depicted, the field of view δ**1** for a horizontally-oriented photodiode **246***e* is extremely wide. Depending on the sensitivity of the photodiode **246***e*, the thickness or translucence of the plastic, and other factors, the field of view δ**1** may approach or exceed 180°. Similarly, due to the orientation of photodiodes **246***a*-**246***d*, their field of view δ**2** approaches near vertical in an upward direction from the autonomous vehicle's housing **212** and is limited below only by the autonomous vehicle's housing **212**. There can be an overlap between the fields of view δ**1** and δ**2** in the longitudinal plane, as depicted in FIG. **4**B.

As illustrated in FIG. **4**A, there can be overlap between the fields of view δ**1** and δ**2**, allowing the autonomous vehicle to detect signals in its operating area. The overlap creates a total field of view for the receiver that approaches the entire volume of the room above the robot housing. Accordingly, this embodiment of the receiver **212**, is well-suited to the exemplary embodiment of the navigation system depicted and described in FIG. **2**, wherein a signal is projected into an entire room. Of course, this receiver **228** could also be used with the system depicted in FIG. **1**. Although installing the receiver closer to or above a top surface of the autonomous vehicle can provide for a wider range of view, this configuration increases a height of the autonomous vehicle slightly and can limit autonomous vehicle travel beneath certain obstacles such as couches, low tables, or the like.

FIG. **4**C depicts an exemplary embodiment of the receiver **328** installed below a surface of the autonomous vehicle housing **312**. The photodiodes **346***a*-**346***e* (as a group referred to as **346**) can be installed in a void **350** or other cavity below the surface of the autonomous vehicle housing **312**. A translucent or transparent plastic cover **312***a* can be fitted over the photodiodes **346**. The cover **312***a* can be secured to the housing **312**, for example, with screws, press-fit connections, or other connectors. Alternatively, the cover **312***a* can be set in place without connectors, allowing easier access to the photodiodes **346** for service or replacement. This lower profile version reduces or eliminates the risk associated with a surface mounted receiver getting stuck below obstacles (as described above).

The construction of the receiver **328** can be similar to that of FIG. **4**A. Four of the photodiodes **346***a*-**346***d* can be installed orthogonal to each other, facing a predefined direction on the autonomous vehicle (e.g., front, back, right, and left). The fifth photodiode **346***e* can be installed orthogonal to the other four photodiodes, facing directly up from a top of the autonomous vehicle. Because the photodiodes **346** are set within the housing **312**, the receiver's overall field of view δ**3** can be limited to a certain degree. In this embodiment, δ**3** equals approximately 120°. The field of view δ**3** can be wider or narrower depending on the depth of installation below the surface of the autonomous vehicle housing **312**. Alternatively, the field of view δ**3** can be modified by utilizing a cover **312***a* having particular effects on signal transmission, such as a fish-eye lens or the like.

FIG. **5**A illustrates an exemplary embodiment of a control schematic **560** for a receiver **528**. The receiver **528** can include a number of independent photodiodes **546***a*-**546***e* (as a group referred to as **546**), pre-amplified and multiplexed into a single microprocessor **562**. As described above, four of the photodiodes **546***a*-**546***d* can be installed orthogonal to each other, facing a predefined direction on the autonomous vehicle (e.g., front, back, right, and left). A fifth photodiode **546***e* can be installed orthogonal to the other four, facing directly up from the top of the robot. Once a reflected signal is received by a photodiode **546**, the receiver **528** determines the frequency of modulation of the signal, the identity sequence, if any, and the envelope of received energy (i.e., the demodulation of energy). These values can be sent to the microprocessor **562**, which can calculate the location of the autonomous vehicle relative to the signals and the identities of the signals. Additionally, if only a single point is detected by the receiver **528** (if for example, the robot's view of the second signal is obstructed), the autonomous vehicle can use this point as a heading. By following this heading, the autonomous vehicle can move within the work area until a second point is detected.

In operation, a receiver (e.g., an infrared receiver) can first measure the "noise floor" of the autonomous vehicle's environment, comprising the amount of energy (e.g. infrared energy) present in the autonomous vehicle's environment, which it sets as the threshold value. This value can represent an average of the values for each photodiode. Any subsequent measurement above this threshold value can trigger an event (e.g., a calculation of point azimuth and elevation). The receiver can then measure the modulation frequency again, searching for an expected increase at 10 kHz (i.e., the frequency of the initial synchronization signal transmitted by the transmitter). If a 10 kHz frequency increase is detected, the autonomous vehicle recognizes the increase as an emitted navigation signal. The autonomous vehicle can then measure the amplitude of the reflected point on all five photodiodes to determine an average value. This value can then be compared to a list of signal frequencies to determine which of the signals has been detected. Alternatively, any detected identity sequence associated with the signal can be compared to a list of transmitter codes or signal IDs stored in a lookup table in the autonomous vehicle's processor memory.

The on-board microprocessor can use the amplitude value to determine the azimuth and elevation of the received signals, which it can then use to determine its location within a working area. To determine the azimuth, the microprocessor enters the values of the two strongest readings from the tour side photodiodes into an algorithm. The algorithm takes the ratio of these two readings to determine the azimuth angle. For example, if the two strongest readings from two photodiodes are equal, the algorithm recognizes that the point is located at an azimuth angle that is directly between the two photodiodes (i.e., at 45°). In a similar algorithm, the amplitude value measured from the strongest side photodiode and the amplitude value measured from the top-facing photodiode value are used to determine the elevation of the signal. These values can be stored in the autonomous vehicle's memory for future reference.

After the receiver has detected at least two points, and determines the azimuth and elevation of each point, it determines its location within the working space. A triangulation algorithm based on the known ceiling height and the azimuth and elevation of the two detected points allows the processor to determine where in the working space the autonomous vehicle is located. Over time, the values of elevation and azimuth between each coded point and specific locations of the autonomous vehicle within the workspace can be stored in the autonomous vehicle's memory, creating a map of the environment in which the autonomous vehicle operates.

In various embodiments, a navigation system **200** as depicted in FIG. **5**B uses an angle-based localization system. Values corresponding to elevation and azimuth are determined by synchronously comparing average amplitudes from the number of detectors arranged on the robot. Of the five detectors, four are arranged in a plane and are angularly spaced by 90° increments. The fifth detector is in the center of the aforementioned four-detector array and aimed so that it is orthogonal to the plane in which the other detectors lie, directed vertically from the autonomous vehicle. Together, this five-element array can have a full or near-full hemispherical field of view.

In the embodiment depicted in FIG. **5**B, all five detectors monitor for amplitude (Step **705**) until an amplitude that crosses a preset threshold is detected (Step **710**). After the amplitude on any detector crosses the preset detection threshold, the frequency of the signal on the strongest detector is measured and compared against known transmit frequencies (Step **715**). If the measured frequency is one of the known transmit frequencies (Step **720**), the next step in the detection process can be executed. If the signal is not a known transmit frequency, the detection process can be aborted (Step **725**) and the signal detected can be declared to be "out of band." Once an "in band" frequency is detected, a time-averaged amplitude for each photo detector can be measured, converted to a binary number, and stored for later processing in a microprocessor memory (Step **730**). Upon storing the five numerical values (one for each photodiode), the azimuth angle can be determined.

Of the four detectors that reside in a single plane, the values of the two strongest signals detected are used to form a ratio to determine the azimuth angle (Step **735**). The ratio of second-strongest signal over the strongest signal is either compared to a look-up table or inserted into a mathematical equation to determine an azimuth angle output. Both the look-up table and the equation represent the overlap of the received sensitivity patterns of two orthogonal detectors with known sensor responses. In this embodiment, the photo detector output is modeled as a fourth-order Gaussian response to angle off of "boresight," a term that generally refers to a vector that is orthogonal to the semiconductor die in the detector package.

To calculate elevation, the strongest signal from azimuth calculation (i.e., the denominator of the ratio) must first be normalized, as if it were on boresight of the respective detector (Step **740**). For example, if the azimuth has been determined to be 10° off of boresight from a given detector, that 10° angle is entered into a look-up table or equation that describes the sensor response of any single photo detector. At zero degrees, the output of this look-up table/equation would be 1.00000. As the angle deviates from zero degrees, the output drops to some fraction of 1.00000 (the normalized value at boresight). For example, if a value of 10° is entered into the equation, the output of this operation can be, for example, 0.99000. The denominator of the azimuth ratio can then be divided by this fractional value in order to scale up, or "normalize" that value to what it would be if the azimuth were actually zero degrees. This normalized value can then be stored in memory and elevation can be determined therefrom.

To calculate elevation, the normalized output from the previous step is used to produce a new ratio with the output from the upward-looking (fifth) detector, so that the numerator is the second-strongest of the two values and the denominator is the strongest of the two values (Step **745**). This ratio

is then entered into the same look-up table or equation from the step above (used to calculate azimuth), thus outputting an elevation angle.

The benefits of this type of navigation system can be numerous. As the autonomous vehicle moves about a working area, measuring the azimuth and elevation of the various points detected, it can create a map of the area, thus determining its location within a given space. With this information, it can fuse data from all of its on-board sensors and improve cleaning or other task efficiency. One way it can do this is to create a map where the high-traffic areas in a house or other building are located (as indicated by readings from the dirt sensor, for example). The autonomous vehicle would then clean the areas it identified as high traffic (and therefore, often dirty) each time it passes over that area, whether directed to or not. The autonomous vehicle may also improve its cleaning function by merging the output from the wheel drop, stasis, bumper, and wall-following sensors to roughly mark areas of entrapment, or where large obstacles exist, so that those areas can potentially be avoided in future runs.

In accordance with various embodiments of the present teachings, another method of improving cleaning efficiency involves selectively programming the autonomous vehicle to clean particular areas, as detailed below. For example, a personal computer or remote control may be used to control the autonomous vehicle. Although the autonomous vehicle can operate without operator intervention, an operator can initially set up the autonomous vehicle, or can direct the autonomous vehicle to operate in particular areas or at particular times. For example, by using more than one transmitter in various rooms on one floor of a house, an operator may be able to direct the autonomous vehicle to clean specific rooms in a particular order and/or at a specific time. The operator could select, in a control program field of a computer program for example, the living room, family room, bathroom, and kitchen areas for cleaning. A remote control for use in accordance with the present teachings is described in more detail with respect to FIGS. **19-22**.

Once commanded (either immediately or on a predefined schedule), the autonomous vehicle can be signaled to begin its cleaning cycle. The autonomous vehicle undocks from its base/charging station and begins cleaning the closest or first room on the programmed list. It can recognize this room and can differentiate it by the coded group of infrared points (e.g., on a ceiling of the room) or the coded signal emitted in the room. After the first room is cleaned, the autonomous vehicle can, for example, check its level of power and return to its charger for additional charging if needed. In accordance with certain embodiments, in order to return to the charger, the autonomous vehicle can follow the point or points on the ceiling back to the base station. Alternatively, the autonomous vehicle can use a known docking behavior. After charging is complete, the autonomous vehicle can traverse roughly back to the place it left off and resume cleaning. This sequence of events continues until all of the programmed rooms have been cleaned. Alternatively, the selection of particular areas to clean could be, for example, made by remote control or by pressing buttons on a control panel located on the base station. By using a personal computer, however, multiple transmitters could communicate with each other and with the base station via power lines using a known communication technology.

An alternative embodiment of the present teachings is depicted in FIG. **6**, wherein an autonomous vehicle uses a number of signals for headings to move from room to room. The autonomous vehicle **612** is moving in a direction M within room A when its power level drops below a predetermined level, requiring its return to a base charging station **622**. Upon crossing the predetermined power level, the autonomous vehicle's receiver **628** searches for a signal from a nearby emitter. As the vehicle is located in room A, it detects the signal **622***a* emitted from transmitter **620***a* and, using the signal **622***a* as a heading, moves directly for that signal **622***a*.

Alternatively, the autonomous vehicle **612** can emit its own coded pulse, to determine if any transmitters are in the area. This coded pulse could "awaken" sleeping or otherwise dormant transmitters, which would then begin their own emission cycle. Alternatively, the pulse can be an audible or visual signal such as a distinct beep, buzz, or visual strobe. Some pulses need not be within the field of view of the transmitter.

The robot **612** will continue to move toward signal **622***a* until one of several events happens at or near doorway **632***a*. In a first event, the autonomous vehicle may determine, based on readings from its photodiodes, that it is directly under the transmitter **620***a*. In a second event, the autonomous vehicle **612** may sense a second signal **624***a*, which may overlap the first detected signal **622***a*. This could occur if the configuration of the emitters, collimators, etc., as described in more detail above, provides overlapping signal patterns between signals **622***a* and **624***a*. In a third event, autonomous vehicle **612** can sense a signal from an entirely different transmitter, in this case signal **622***b* from transmitter **620***b*. Other events are also contemplated, as suitable for a particular application. The occurrence of an event presents the autonomous vehicle **612** with any number of behavioral, functional, or other options. For example, each coded signal may serve as a unique marker for a different working space. Upon detecting the unique marker associated with a particular working space, the autonomous vehicle may alter its cleaning function. Thus, if room A is carpeted but room B is uncarpeted, the autonomous vehicle can adjust its cleaning as it moves from room A to room B. Upon detecting a second signal (in this case, signal **622***b*) the autonomous vehicle can, in certain embodiments, completely disregard the first signal **622***a* received when its return to the base station **622** began. Using new signal **622***b* as a heading, it begins moving toward that signal **622***b*. The autonomous vehicle **612** can, in certain embodiments, check its battery level at each event, storing that value in its microprocessor. Over time, the autonomous vehicle can thereby create a table of battery levels at each event (and battery level change from event to event), and be able to accurately determine precise battery power remaining at each transmitter location.

Once the autonomous vehicle is traversing room B (shown in phantom as **612'**), it will eventually determine, based on battery level, time, or other factors, to follow the heading provided by signal **622***b*, and continue its return to its base station **622**. The autonomous vehicle **612** can follow the heading until an event occurs at or near doorway **632***b*. Again, the event can be detecting a strength of signal **622***b*, indicating that the autonomous vehicle is directly below the transmitter, detecting an overlap signal from **624***b*, or detecting a new signal **622***c*. The autonomous vehicle **612** can again perform any of the behaviors described above: check and store its battery level; change cleaning characteristics; etc.

Once in room C, the autonomous vehicle can begin following the heading provided by signal **622***c*. At or near the doorway **632***c* to room D, an event may direct the autonomous vehicle to perform any number of behaviors. Alternatively, the autonomous vehicle can move directly to charging station **622**, guided by emitted signal **626** or another signal or program.

During its return to the base station, as the autonomous vehicle **612** moves from room A to room B to room C and so on, it detects and stores information about each coded signal

that it detects along its route. By storing this information, the autonomous vehicle can create a map, using the coded signals as guideposts, allowing it to return to its starting location in the future. After charging, the autonomous vehicle can return to the room it was working in prior to returning to its base by comparing the detected signals and their strengths to the stored information.

FIGS. **7-9** depict schematic circuit representations for exemplary embodiments of various components of an infrared signal transmitter, namely an AC-DC converter, a microcontroller and support circuitry, and LED drivers. More specifically, FIG. **7** illustrates an electronic circuit that takes 120 VAC 160 Hz line voltage and converts it to a regulated +5 VDC supply. This supply can be used to power the microcontroller and associated circuitry of the transmitter depicted in FIG. **8**. In addition to power conversion, this circuit can also provide an isolated digital logic signal to the microcontroller, whenever a "zero-crossing" in the AC line input is detected.

FIG. **8** illustrates a transmitter microcontroller and support circuitry (i.e., a clock oscillator and an in-circuit serial programming port). In addition, there is a circuit that allows a user-initiated button press to project visible light from a pair of LEDs, co-located with a pair of IR LEDs, onto a remote surface for the purpose of assisting the user in aiming the infrared signal points.

FIG. **9** illustrates two channels of an IR LED driver. Each driver can control a preset constant current into a single IR LED, which can then emit near-infrared light that can be collimated by an external lens and projected onto the remote surface. Each IR LED can be modulated and pulse-coded independently of the other. This allows the microcontroller in the autonomous vehicle to discern between the different transmitter signals, to determine which detected signal is which.

FIGS. **10-14** depict schematic circuit representations in accordance with certain embodiments of various components of a vehicle-mounted infrared receiver, namely DC-DC linear power converters, a five channel preamplifier, a multiplexer and programmable tuned amplifier, detectors, and a microcontroller and associated peripherals. More specifically, FIG. **10** depicts two independent linear voltage regulators. One of the regulation circuits can be switched ON-OFF via a microcontroller to conserve battery power during a sleep mode.

FIG. **11** depicts five independent preamplifiers that can convert respective photodiode output currents into voltages of much larger magnitudes. Each preamplifier is built using an operational amplifier in a transimpedance topology. This allows the preamplifiers to be configured with low noise. Also, there is an active feedback circuit that is used to null large photodiode current offsets caused by exposure of the circuit to sunlight and other strong low-frequency light sources.

FIG. **12** illustrates an exemplary multiplexer and programmable tuned amplifier for the receiver. This circuitry can be segregated into three functional blocks. The first block is a multiplexer that receives signals from the five photodiode preamplifiers and outputs one of the signals to a programmable attenuator, as commanded by the receiver's microcontroller. The second block is a programmable attenuator that can be used to reduce the overall receiver gain, to deal with the large dynamic range of received signals. As depicted herein, there are two digital inputs from the microcontroller, which permits four discrete gain levels to be selected. The third block is a tuned, band-pass amplifier that can provide the bulk of the voltage amplification to signals that fall within the circuit's pass band.

FIG. **13** depicts an exemplary embodiment of two detectors that can be used in the receiver. The first detector is a rectifying, envelope detector with integral voltage gain, and can be used to strip modulation frequency and provide a signal envelope to the microcontroller's analog to-digital converter. The signal envelope can be used the by microcontroller to determine the magnitude of the received signal. The second detector is a voltage comparator, which can be used to "square up" received pulses and convert them to a CMOS logic level, thereby allowing the microcontroller to extract digital data from the received signals.

Lastly, FIG. **14** illustrates the microcontroller and its peripherals. The peripherals can include a clock oscillator, ICSP port, voltage supervisor/reset generator, and RS-232 level serial port for interfacing with a host personal computer or a main robot processor.

Accordingly, the navigation system can be operationally robust and adapted to compensate for variances in infrared energy. For example, if the autonomous vehicle is operating in an environment with high base infrared readings (e.g., a space with a large number of fluorescent lighting fixtures or windows that allow entry of sunlight), the autonomous vehicle can distinguish the infrared signals generated by the transmitter from the infrared noise present in the space. Similarly, the receiver can distinguish between other off-band signals, such as infrared remote controls. In such cases, establishing an initial threshold value of infrared energy and emitting a predefined, known, modulated infrared signal from the transmitter overcomes these environmental disturbances. Additionally, the transmitter can be tuned to emit a sufficiently strong infrared signal to accommodate surfaces with varied reflectivity.

FIGS. **15A-15C** illustrate side, bottom, and end views, respectively, of an exemplary embodiment of a transmitter **200** having a thin rectangular housing and configured for placement in a variety of locations including a top surface of a doorway as illustrated in FIGS. **2**, **6**, **17**, and **18**. In the illustrated embodiment, an emitter **222**, **224** is located adjacent each edge E_L, E_R of the transmitter **200**. In accordance with certain embodiments of the present teachings, each emitter can comprise a lens **222***d*, **224***d* as described above to focus and direct the emitted signal. The present teachings also contemplate the transmitter **200** comprising a third emitter **226** with a lens **226***d* to focus and direct the emitted signal. The illustrated transmitter **200** also comprises a battery **230** and a printed circuit board **240**. As discussed above, the battery **230** can provide power to the transmitter **200** while allowing the transmitter **200** to be located without regard to proximity of power supplies such as wall outlets. Other portable power sources such as capacitors can also be used instead of, or in addition to, the battery. The printed circuit board **240** can be employed to modulate and code the emitted signals, and to provide power conversion for wirelessly charging the battery **230** or other power source. An antenna **250** can be utilized to intercept fields for conversion to current for wirelessly charging the battery, as described in more detail below.

Wireless charging in accordance with the present teachings can comprise, for example, RF scavenging or magnetoresonance. Wireless charging via RF scavenging can be accomplished as disclosed in U.S. Patent Publication No. 2009/0102296, the entire disclosure of which is incorporated herein by reference. The antenna **250** (e.g., a RF wireless communication antenna) can facilitate both energy harvesting and wireless communication for the transmitter **200** and, to facilitate energy harvesting, can harvest RF energy from a variety of sources including, for instance, medium frequency AM

radio broadcast, very high frequency (VHF) FM radio broadcast, cellular base stations, wireless data access points, etc. The energy can be harvested from that naturally available in the environment (work area) or can be broadcast by a source such as an RF signal emitter on the autonomous vehicle or on another device such as a base station or a dedicated emitter. FIG. **23** schematically illustrates an embodiment of the present teachings wherein an autonomous vehicle **12** includes a RF signal emitter **360** that directs an RF signal toward the transmitter **200** for harvesting to ensure adequate RF energy for recharging the battery **230** or other power source. The printed circuit board **240** can serve to convert the harvested RF energy into a usable form, for example AC voltage or DC voltage. The printed circuit board **240** can also regulate the converted power.

Certain embodiments of the present teachings contemplate wireless charging via strongly coupled magnetic resonances, or magnetoresonance. Such wireless charging is described in detail in Kurs, et al., *Wireless Power Transfer via Strongly Coupled Magnetic Resonances*, Science, Vol. 317, pp. 83-86 (Jul. 6, 2008), the entire disclosure of which is incorporated herein by reference. For wireless charging via magnetoresonance, the antenna **250** can comprise, for example, a capture coil that can capture and convert magnetic energy to AC voltage or DC voltage. The magnetic energy captured by the capture coil can be supplied by a power source such as a highly resonant magnetic source. The power source can be located, for example, on the autonomous vehicle (in a scenario such as that illustrated in FIG. **23**), on a dedicated device, or on a base station for the autonomous vehicle.

One skilled in the art will appreciate that the transmitter **200** can derive its power from a source other than a battery, for example from a wall plug or by direct connection to a building's power supply. Also, the emitters can have differing locations on the transmitter, and need not be combined with a lens as illustrated. The size of the transmitter can vary in accordance with functional considerations (e.g., being large enough to house its components) as well as aesthetic considerations (e.g., minimizing size to be less obtrusive).

FIGS. **16**A-**16**C illustrate side, bottom, and end views, respectively, of another exemplary embodiment of a transmitter **300** having a thin rectangular housing and configured for placement in a variety of locations including a top surface of a doorway as illustrated in FIGS. **2**, **6**, **17**, and **18**. In the illustrated embodiment, an emitter **322**, **324** is located adjacent each edge of the transmitter **300**. In accordance with certain embodiments of the present teachings, each emitter can comprise a collimator **322***e*, **324***e* and a lens **324***d* (see FIG. **16**C) as described above to focus and direct the emitted signal. Although a third emitter is not illustrated in this embodiment, the transmitter can comprise at least one additional emitter and can employ a lens and/or collimator thereon to focus and direct the emitted signal. The illustrated exemplary transmitter **300** also comprises a battery **330** and a printed circuit board **340**. As discussed above, the battery **330** can provide power to the transmitter **300** while allowing the transmitter **300** to be located without regard to proximity of power supplies such as wall outlets. The printed circuit board **340** can be employed to modulate and code the emitted signals, and to provide power conversion for wirelessly charging the battery **330** or other power source. An antenna **350** can be utilized to intercept magnetic or RF fields for conversion to current for wirelessly charging the battery **330**, as described above with respect to FIG. **15**.

One skilled in the art will appreciate that the transmitter **300** can derive its power from a source other than a battery, for example from a wall plug or by direct connection to a building's power supply. Also, the emitters can have differing locations on the transmitter, and need not be combined with a collimator and/or a lens as illustrated. The size of the transmitter can vary in accordance with functional considerations (e.g., being large enough to house its components) as well as aesthetic considerations (e.g., minimizing size to be less obtrusive).

FIG. **17** illustrates a transmitter **200** mounted on a top surface T of a doorway DW or other passage between two areas. In the illustrated embodiment, because the transmitter **200** is placed at a high position within the room or work area, the emitted signals should not be directed upward toward the ceiling and instead should be directed toward the portion of the room through which the autonomous vehicle **12** travels. In accordance with various embodiments, the emitted signals can be coded and modulated as discussed above, so that the autonomous vehicle **12** can recognize the transmitter for localization and/or navigation purposes. In addition, in accordance with certain embodiments, the emitted signals can include information for the autonomous vehicle **12**, such as information instructing the autonomous vehicle to adjust its cleaning behavior.

In embodiments of the present teachings employing more than two emitters, the signals can be utilized, e.g., with collimators or lenses, to distinguish different areas within a room. Such a configuration allows the autonomous vehicle **12** to sense its relative location within a room and adjust its cleaning behavior accordingly. For example, a signal could mark an area of the room that an autonomous vehicle would likely get stuck in. The signal could allow an autonomous vehicle to recognize the area and accordingly not enter it, even though it might otherwise be able to do so unimpeded. Alternatively or additionally, different signals could mark areas that require different cleaning behaviors (e.g., due to carpeting or wood floors, high traffic areas, etc.).

The transmitters **200**, **300** as illustrated in FIGS. **15**A-**15**C and FIGS. **16**A-**16**C, respectively, can function in a manner similar to transmitter **120** in FIG. **2**, as described above, with the additional emitter(s) allowing more functionality, as described above, such as indicating areas requiring different cleaning behaviors. The transmitters **200**, **300** can also function in a manner similar to the transmitters illustrated in FIG. **6**, and particularly those located within the doorway/room transitions in FIG. **6**.

FIG. **18** illustrates the autonomous vehicle of FIG. **17** passing through a doorway DW, and additionally illustrates an exemplary embodiment of the present teachings utilizing a remote control **370** to communicate with the autonomous vehicle **12** and/or the transmitter **200**. An exemplary embodiment of a remote control **370** is disclosed in more detail in FIGS. **19**A-**22**.

As illustrated in FIGS. **19**A-**19**C, the remote control **370** can include one or more power buttons **340** for powering ON/OFF the remote control **370** the transmitter **200**,**300**, and/or the autonomous vehicle **12**. In addition, the remote control **370** can include a display **310** (e.g., a liquid crystal display) and one or more input devices **320**, **330** such as buttons and/or a toggle pad. FIGS. **19**A-**19**C show the remote control **370** being used to set up an autonomous vehicle for cleaning. In FIG. **19**A, the display **310** displays a variety of room types to be cleaned by the autonomous vehicle. In the illustrated embodiment, the user can locate himself and the remote control **370** in a work area to be cleaned and select from a number of room type choices, such as bedroom, office, kitchen, utility room, living room, dining room, bathroom, and hallway. The system can identify this room via an encoded and/or modulated emitted signal from a nearby

transmitter. The user selects one of the room types by pressing an adjacent button **320**. Thereafter, the display **310** can acknowledge the user's selection and automatically connect to a controller (see FIG. **19**B), such as a personal computer, to allow the user to provide a specific name for the room. In other embodiments, the remote control can correlate the coded emitted signal with the chosen/assigned name and allow a user to choose whether to engage in specific room naming (e.g., via input **320**) or just assign a predetermined name to the room such as bedroom **1**, office **1**, kitchen **1**, etc. Once a room has been assigned an appropriate name, the remote control can allow the user to enter additional names or continue other aspects of setup. In FIG. **19**C, the remote control **370** displays the rooms that have been registered and allows the user to select which rooms are to be cleaned. In the illustrated exemplary embodiment, the user can select one or more of the registered rooms by pressing an adjacent button **320**. The system can then determine the order of the rooms to be cleaned and the start time (e.g., immediately), or can allow the user to determine the order of the rooms to be cleaned and/or the start time. In certain embodiments, the system can allow the user to select a start time for each selected room.

Another input device **330**, shown in the illustrated embodiment as a toggle pad or toggle button, can allow the user to direct the autonomous vehicle to perform a number of functions. For example, the user can press a center "CLEAN" portion of the toggle button to direct the autonomous vehicle to begin cleaning immediately, or can select the right "DOCK NOW" button to direct the autonomous vehicle to begin a homing behavior and dock. A top "SCHEDULE" button can be pressed to allow the user to select a schedule of rooms and/or times for cleaning, an exemplary process for which is illustrated in FIGS. **20**A-**20**C. The user can also select the left "MODES" button to select among a variety of available cleaning modes such as spot clean, deep clean, area rug, drive now, etc. as illustrated in FIG. **21**A. The modes displayed in FIG. **21**A can be selected by pressing a button **320** adjacent a desired mode. In certain embodiments, after a mode has been selected, the remote control **370** can provide further instructions to the user. For example, if an "area rug" mode has been selected, the remote control **370** can display instructions confirming that the autonomous vehicle is in "area rug" mode and instructing the user to place the autonomous vehicle on the area rug and then press the central "CLEAN" button. In the illustrated embodiment of FIG. **21**B, the remote control **370** confirms that the "ROBOT WILL CLEAN THE RUG ONLY." In another example, if a "DRIVE NOW" mode is selected, the remote control **370** can allow the user to drive the vehicle. In accordance with FIG. **21**C, the remote control **370** can inform the user that the autonomous vehicle is in a "DRIVE NOW MODE" and instruct the user to press certain buttons to drive the robot. For example, the top "SCHEDULE" button can be pressed to turn the autonomous vehicle forward, the left "MODES" button can be used to turn the vehicle to the left, the right "DOCK NOW" button can be used to move the vehicle to the right, and the bottom "SETUP" button can be used to move the vehicle backward. One skilled in the art will appreciate that other buttons can be used to drive the vehicle, such as a dedicated drive toggle or input buttons **320**. In certain embodiments, the remote control **370** can also inform the user how to exit the "DRIVE NOW" mode, such as by pressing a portion of the toggle button **330**.

FIGS. **20**A-**20**C illustrate an exemplary embodiment of cleaning schedule displays that can be utilized when the user has pressed the top "SCHEDULE" portion of toggle button **330**. In the illustrated exemplary embodiment, cleaning frequency choices are first displayed for user selection. For example, twice daily, daily, three times per week, weekly, bi-weekly, or monthly can be selected. In certain embodiments, a "CUSTOM" selection can also be made. Users select a frequency by pressing a button adjacent their preferred frequency. In accordance with certain embodiments, once a frequency has been selected or, if "CUSTOM" is selected, the remote control can display the days of the week for cleaning (see FIG. **20**B). The user can select an appropriate number of desired days by pressing the button **320** adjacent those days. In addition, in accordance with certain embodiments, the user can select a time for cleaning for all selected days or a time for cleaning for each selected day. Thereafter, as illustrated in FIG. **20**C, the user can be prompted by the display **310** to select one or more rooms for cleaning at the desired date and time. In accordance with various embodiments of the present teachings, a user could select "CUSTOM" and set a date and time for each room registered in accordance with FIGS. **19**A-**19**C, or could select a predefined schedule as illustrated in FIG. **20**A and personalize that selection by choosing days and times if desired.

In accordance with certain embodiments of the present teachings, the remote control **370**, can also display a status screen such as that illustrated in FIG. **22**. The status screen can have a variety of formats for informing the user how much of a scheduled cleaning has been completed. The status screen can be accessed in a variety of ways via manipulation of the remote control **370**, or may appear in the manner of a screen saver when the remote control **370** is not being used for controlling an autonomous vehicle or inputting data. One skilled in the art will understand that the selections facilitated by the remote control **370** in FIGS. **19**A-**22** can also be accomplished via other devices, such as a handheld PDA, a cellular phone, or a laptop or other similar computing devices.

Other embodiments of the present teachings will be apparent to those skilled in the art from consideration of the specification and practice of the teachings disclosed herein. It is intended that the specification and examples be considered as exemplary only, with a true scope and spirit of the present teachings being indicated by the following claims.

What is claimed is:

1. A method performed by a device remote from an autonomous vehicle, the method comprising:

receiving input from a user specifying a task for the autonomous vehicle, wherein the task involves having the autonomous vehicle traverse an area;

sending one or more instructions to the autonomous vehicle to begin the task; and

displaying, on a display screen of the device, a status screen indicating how much of the task the autonomous vehicle has completed, wherein displaying the status screen comprises coloring a floor plan of the area as the autonomous vehicle traverses the area so that one or more colored portions of the floor plan illustrate where the autonomous vehicle has been and one or more uncolored portions of the floor plan illustrate where the autonomous vehicle has not been.

2. The method of claim **1**, wherein the autonomous vehicle is a cleaning robot, and wherein the task is a cleaning task.

3. The method of claim **1**, wherein displaying the status screen comprises displaying a percentage of the task that has been completed.

4. The method of claim **1**, wherein receiving input from the user comprises receiving scheduling information for scheduling the task, and wherein sending the one or more instructions to the autonomous vehicle comprises sending the one or more instructions according to the scheduling information.

5. The method of claim 1, wherein displaying the status screen comprises displaying the status screen in the manner of a screen saver when the device is not being used for controlling the autonomous vehicle or inputting data.

6. A device comprising:

one or more input devices; and

a display,

wherein the device is configured to control a remote autonomous vehicle by performing operations comprising:

receiving, by the one or more input devices, input from a user specifying a task for the autonomous vehicle, wherein the task involves having the autonomous vehicle traverse an area;

sending one or more instructions to the autonomous vehicle to begin the task; and

displaying, on the display, a status screen indicating how much of the task the autonomous vehicle has completed, wherein displaying the status screen comprises coloring a floor plan of the area as the autonomous vehicle traverses the area so that one or more colored portions of the floor plan illustrate where the autonomous vehicle has been and one or more uncolored portions of the floor plan illustrate where the autonomous vehicle has not been.

7. The device of claim 6, wherein the autonomous vehicle is a cleaning robot, and wherein the task is a cleaning task.

8. The device of claim 6, wherein displaying the status screen comprises displaying a percentage of the task that has been completed.

9. The device of claim 6, wherein receiving input from the user comprises receiving scheduling information for scheduling the task, and wherein sending the one or more instructions to the autonomous vehicle comprises sending the one or more instructions according to the scheduling information.

10. The device of claim 6, wherein displaying the status screen comprises displaying the status screen in the manner of a screen saver when the device is not being used for controlling the autonomous vehicle or inputting data.

11. A method performed by a device remote from a cleaning robot, the method comprising:

displaying, on a display screen of the device, a plurality of available cleaning modes for the cleaning robot;

receiving input from a user selecting a cleaning mode for the robot, wherein the selected cleaning mode is an area rug cleaning mode;

based on the selected cleaning mode, displaying instructions to the user on the display screen, wherein displaying instructions to the user comprises displaying instructions for the user to place the cleaning robot on an area rug;

receiving further input from the user confirming that the cleaning robot is ready; and

sending one or more instructions to the cleaning robot to enter the selected cleaning mode.

12. The method of claim 11, further comprising displaying, on the display screen, a confirmation to the user that the cleaning robot will clean the area rug only.

13. The method of claim 12, wherein the plurality of available cleaning modes includes a spot clean mode, a deep clean mode, an area rug mode, and a drive now mode.

14. A device comprising:

one or more input devices; and

a display,

wherein the device is configured to control a cleaning robot by performing operations comprising:

displaying, on the display, a plurality of available cleaning modes for the cleaning robot;

receiving, by the one or more input devices, input from a user selecting a cleaning mode for the robot, wherein the selected cleaning mode is an area rug cleaning mode;

based on the selected cleaning mode, displaying instructions to the user on the display screen, wherein displaying instructions to the user comprises displaying instructions for the user to place the cleaning robot on an area rug;

receiving further input from the user confirming that the cleaning robot is ready; and

sending one or more instructions to the cleaning robot to enter the selected cleaning mode.

15. The device of claim 14, the operations further comprising displaying, on the display screen, a confirmation to the user that the cleaning robot will clean the area rug only.

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